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13. ABSTRACT *(Maximum 200 words)* The objectives were to determine and document the technical and economic feasibility of using ultrasonic technology for inspection of food pouches to determine package integrity. Literature searches indicated successful use in some industries, but no experience in the packaged food industry. The alternatives are visual human inspection machine vision optical inspections, vacuum residence and decay measurements, and perhaps others. Current visual methods by human inspectors are less than totally successful, and the tasks are tedious. This project indicated that technically the ultrasonic techniques can be used for inspection of package integrity, but economically it is not as desirable as other technologies, especially considering that humans are now on hand, trainable, and flexible. Under the current conditions, there will be no further pursuit of this technology for inspection.

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Executive Summary

The objective of this study was to determine the technical and economical feasibility of using ultrasonic technique for 100% on-line inspection during production of pouches and other containers.

To better understand the inspection issues and industry needs, a review of literature regarding the potential inspection techniques was conducted. This review revealed that leak testing and machine vision systems remain predominant in the package inspection field. Leak testing is considered the lead technology and continues to be used for package inspection. Vision system is also widely used and the main applications are in pharmaceutical industry sector. Ultrasonics , however, is very new to the field of package inspection and recent papers in ultrasonics have shown that this is a promising technology. Publications in the ultrasonic field present preliminary results and the conflicting requirements between in-line implementation, detection resolution and the system cost are discussed.

In this study, feasibility of using ultrasonic for MRE inspection was demonstrated showing that ultrasonic array system developed by ALCAN was capable of detecting all seal defects (contaminant, short seal, foldover) supplied by Sterling Foods Inc. This is not conclusive and relies on a limited number of MRE samples. To examine the applicability and sensitivity of the ultrasonic technique, a controlled laboratory study was conducted using samples prepared with known seal defects such teflon film, wire and seal conditions such as spillage due to overfill and short seal. The preliminary results of this laboratory work confirmed that ultrasonic is capable of detecting the defects in the seal and is a nondestructive tool to characterize the heat seal layer. In addition, a very preliminary review of a new ultrasonic technique, namely air-coupled ultrasonic, showed that this is technology may have future potential.

In summary, Leak testing is the suggested approach to package integrity inspection. However, the inspection speed and sensitivity to leaks remain a limiting factor for in-line implementation. The leak testing may be difficult to implement for vacuum-packed MRE's. With regards to the application of ultrasonics, MRE seals can be inspected by the ultrasonic technique. The adaptation of the technique for in-line use has shown to be promising in detecting defect samples supplied by Sterling, despite the fact that the in-line prototype was designed for a different package type. The main issues that need further work are to repeat the test on MRE's with a custom-designed array for MRE seals. Future work needs to determine a more precise costing of an ultrasonic array system optimized for the desired resolution.

Conclusion: From this study we conclude that technically, ultrasonic technology is feasible for the inspection of retorted MRE pouches, and may offer more accuracy and efficiencies than are currently available by other methods. However, economically, the present state of maturity of the technology will require substantial capital investment, which may or may not provide an acceptable return on investment or other measurable benefits. The final decision should depend on the circumstances and future plans of each individual producer.

Recommendation: Several significant factors and variables have been discussed in this report. Upon consideration, some producers who may suspect that they have a need for the degree of accuracy and efficiency that ultrasonic inspection could provide, should seek more information. It is recommended that they gather the baseline statistics related to their current processes and then contact the authors of this report for the purposes of further analysis and possible solutions.

FEASIBILITY STUDY: 100% ULTRASONIC POUCH INSPECTION

I. INTRODUCTION

a. Objective. The primary objective of this report is to summarize the results of a study to determine the technical and economic feasibility of using an integrated 100% ultrasonic inspection system, on-line, to produce pouches or other containers. Additionally, this report provides an evaluation and the results of a study of other potential inspection techniques to test integrity of food pouches.

b. Background. The use of flexible and semi-rigid packages for food and medical products is rapidly growing. Typically, these packages are heat sealed by applying heat to two polymer layers held together under die pressure for a specific period of time. The diversity of polymer materials and their properties has contributed to a market, which offers an application specific packaging materials. The packages are made from laminated sheets, which incorporate metal foil or polymeric oxygen-barrier layers. Such packages are also readily retortable providing shelf stable products to customers. Therefore, one of the key issues to package integrity is the quality of the seal.

Destructive methods are commonly used to inspect the seal integrity of packages. However, destructive test procedures incur significant cost due to loss of time, product and package material. This has resulted in an increased demand for reliable, 100%, on-line, non-destructive testing methods.

Project Team

The results reported here are a compilation of the contributions from the following project team:

-	OSU, Food Science Department,	Professor Howard Zhang and Ms. Zehra Ayhan
-	EWI,	Dr. Bahram Farahbakhsh and Ms. Constance Reichert
-	PTI, (under subcontract to EWI)	Mr. Anthony Stauffer and Dr. Micheal Kneller
-	Sterling Foods, Inc.,	Mrs. Christine Dietzel
-	Natick,	Dr. Patrick Dunn, Mr. Robert Trottier & Peter Sherman

Project Task Breakdown

To meet the objective of this feasibility study, a sequence of tasks have been accomplished, these are:

- Review of reported inspection techniques
- Survey of industrial equipment supplier
- Conduct feasibility study on laboratory and production-line samples
- Understand Sterling Foods requirements
- Develop an implementation plan

Literature Review

A literature review describing the status of the package testing techniques has been conducted to determine existing and available inspection approaches, their capabilities, advantageous and disadvantageous. Evaluation of destructive and non-destructive methods, definitions and classifications of defects can be seen in appendix I and II.

Equipment Supplier Survey

A survey of the inspection equipment suppliers for packaging and related technologies has been conducted. The results of this survey are reported in Appendix III.

II. Feasibility Tests

In order to determine the feasibility of using ultrasonics to inspect MRE pouches, a two stage systematic approach has been adopted.

The first stage involved conducting laboratory control tests to determine the sensitivity of the technology to seal defects. To conduct the work under control condition, EWI's computerized ultrasonic immersion system was used to test control samples with known and deliberate seal defects followed by defect characterization. This necessary first stage was intended to provide a basis for interpretation and correlation of ultrasonic signals and seal defects.

In the second stage, ALCAN's existing technology designed for in-line implementation. was used to assess the capabilities and limitations of this technology to test actual MRE pouches from Sterling Foods Inc.. ALCAN system was designed specifically for heat seal laminates of semi-rigid containers using custom ultrasonic arrays in the shape of the seal. For the work, the arrays were replaced with a prototype array to determine whether the system can differentiate a 'good' MRE seal from a defective one.

In addition, an evaluation of the Pti's air-coupled ultrasonic system which is a novel approach, was conducted.

For completeness and comparison, since leak testing of MRE's is the technique used mostly at the packaging plants, a feasibility of this technology is also determined and the results are reported here.

What is a typical MRE?

To understand the inspection requirements for the MRE, it is important to consider the material and design of such packages and their production sequence. In this study, Sterling Foods Inc. provided the guidance in terms of inspection and implementation of an in-line inspection, which are probably similar to the inspection of other MRE fills. At Sterling Foods, the production process consists of baking a variety of cakes, which are then form-fill-sealed in a pouch with foil barrier laminates on a moving web. Each laminate is a 3-ply flexible material and has a 0.003-in. thick external polymer with 0.0007-in. thick aluminum and 0.0009-in. thick polypropylene being on the inside of the package. The polypropylene layers are in contact at the four edges of the pouch and the heat seal region is ~1/2-in. wide. The pouches are heat-sealed on-line at 1.5 seconds contact time. Depending on the nature of the content, pouches are vacuum-packed or sealed with an inert gas. After production, individual pouches are visually inspected on-line for obvious external signs of defects. In addition, samples of production are collected periodically and visually inspected for a range of defects as listed in Apppendix II. Common observations are open seals, channel leaks, short seal, stress-cracks, lack of vacuum and foldovers.

III. Ultrasonic Technique

a. Introduction. Ultrasonics is known a as nondestructive and non-invasive tool for industrial and medical applications. In the medical field, ultrasonic is used routinely for fetal observation and opthalmic examination. Ultrasonic application for imaging under water and through opaque materials, particularly to find objects or detect cracks, disbonds or delamination is also familiar. In all common applications of ultrasonics, the ultrasonic waves are generated by making a crystal or a special ceramic with piezo-electric properties vibrate under an oscillating electric field. The vibrations are then coupled to the object by providing a contact between the emitting transducer and the object. To improve the efficiency of vibrational energy transfer, a viscous film is established between the transducer and object. A common practice for controlled inspection consists of immersing the object in a water bath or flood the ultrasonic beam with water using water jets. If the transmitter is also used as a receiver the ultrasonic technique is referred to as pulse-echo. In this case, the reflected signal contains information about the material properties of the object and the size, location and the type of discontinuities in the object. This reflected signal is displayed as A-scans.

An A-scan is an x-y display of ultrasonic intensity (x) plotted against its time of propagation and reflection through the material thickness(y). In the case of package inspection, the discontinuities could be trapped food in the seal and foldover. Indeed, ultrasonic propagation through the seal is affected directly by the density and elasticity of the seal and provides key information about the quality of the seal, its peelability and the thickness of the seal. By scanning the transmitting/receiving transducers, the whole object can be mapped. The information can be displayed as C-scans.

C-scans are more like a plan view from the above and provide depth information by using a color or a gray scale code. This color scale may be directly associated to the time of arrival of the echo signal and in this case depth is inferred using the velocity of ultrasonic propagation in the material. In the above description, ultrasonic waves are used to find anomaly in the object, a common application is also to measure thickness of an object.

IV. EWI Ultrasonic Immersion System

a. Basic Laboratory Equipment. Non-contact, immersion type ultrasonic testing using high frequency sound waves was evaluated for defect detection in the seal area of semi-rigid cups and trays. Sound waves generated by a 20 MHz ultrasonic transducer were transmitted through the material. At disparities within the seal, sound waves were reflected back to the receiver. Received ultrasonic signals, or echoes, were used to develop A-scan and C-scan representations. Discontinuities in the seal, non-uniform seal, non-bonded areas and embedded foreign materials such as wire and Teflon in the seal, contaminated seal and abrasion were observed in the C-scan and A-scan representations based on reduced signal strengths.

EWI Immersion System This system (SONIX DPR 35-S) is a general-purpose computer controlled ultrasonic integrated system (Figure 1). Any ultrasonic scanning system has three basic components: pulser/receiver data acquisition, transducer and motor controller. In the EWI system, pulser/receiver is controlled by a host personal computer. Pulser/receiver generates electrical pulses, which are transmitted to an ultrasonic transducer. The transducer converts electrical excitation pulse to an ultrasonic pulse, which is propagated into a test material or medium. In pulse-echo mode operation, acoustic echoes reflected back from interfaces within the material or medium are converted by the transducer back into electrical signals for amplification and filtering by the receiver. The receiver amplifies and filters the signal for display on a digitizing oscilloscope.

Transducer (Panametric Inc.) used in the immersion tests is a ¼ inch diameter device, which generates by the ultrasonic pulses with 20MHz center frequency. Ultrasonic pulses produced are propagated into the test material. The same transducer receives the reflected echoes and converts it into electrical impulses.

The scanning of samples is done by the scanning bridge and controlled by the immersion system x-y-z motor

b. Samples for Immersion Testing. Semi-rigid plastic containers with heat-sealed lid formed by a Benco aseptic packaging machine were inspected for seal integrity using the ultrasonic immersion testing method. Containers were formed using laminated roll-stock material (HIPS as outer layer PVDC as barrier layer and LDPE as inner layer). Containers sealed under different sealing temperatures, containers with Teflon strands or wire in the seal, containers with short seal and overfilled containers were scanned and the results were represented as A-scan and C-scan.

The immersion system was also used to scan the polymeric trays, supplied by NATICK, with contaminated seal and seal abrasion, to determine whether these seal defects are detectable with ultrasonic.

c. **Procedure for Immersion Testing.** Both the transducer and the package to be tested were immersed in water. Ultrasonic pulse, generated by the piezoelectric type transducer, was propagated into the test material. At interfaces such as the front face and the back surface or internal defects, sound waves were reflected back to the receiver. Received echo signals were amplified and then displayed on a digitizing oscilloscope.

The above description summarizes the basic concepts of ultrasound and its application using piezoelectric transducers that are fluid coupled to the object being inspected. This method of generation, detection and coupling of ultrasonic may be called conventional ultrasonic technique. Such a technique, because it requires immersing the package in a fluid bath to achieve ultrasonic coupling and not suited to packaging production lines.

V. Results from EWI Ultrasonic Testing

EWI ultrasonic immersion system was used to develop an understanding of the ultrasonic detection limit, sensitivity and the effect of defect type and size on the ultrasonic signals. As discussed earlier, two sample types, semi-rigid plastic containers samples with laminated lid and polymeric trays with heat seal lids, were tested with the immersion system.

Results showed that wire with the thickness of 0.005 inch in the seal area is detectable by the ultrasonic imaging (Figures 4-6). A gap is observed on C scan (Figure 4) where wire was implanted. Reference signal was recorded from the undisturbed region of the seal (position A in Figure 4). Signal from the disturbed region of the seal (position B in Figure. 4) where the wire was placed was evaluated relative to the reference signal. A decrease in amplitude of the signal occurred for position B compared to A when the wire is embedded in the seal (Figures 5, 6).

Signal amplitude was dropped from 48.8% to 16.5% when wire was implanted in the seal (Figures 5 and 6). Optical microscopic pictures were taken from these two positions are presented in Figures 7 and 8 respectively showing undisturbed and disturbed positions much closely. Results showed that approximately 50% signal drop is observed when wire is in the seal compared to reference signal at undisturbed regions of seal area.

C-scan and A-scan results of a semi-rigid cup with Teflon in the seal can be seen in Figure 9. Teflon defects in the seal are not so readily detectable as wire defects. As an example, among 10 containers, Teflon was detected at the seal area of only three containers. Figure 9 was the best representative where Teflon was detected A signal from undisturbed area (position A in Figure 9) was obtained as 43.3% where Teflon was observed in the seal (position B in Figure 9).

Short seal was also detected easily with ultrasonic scanning as can be seen in Figure 12. Five semi-rigid cups with short seal were scanned and all were detected. Shorts seal was observed between 3 o'clock and 6 o'clock positions (Figure 12) where loss in signal amplitude was observed relative to other positions (9, 12, 3 and 6 o'clock positions as can be seen in Figure 10).

Containers sealed under different sealing temperatures were also inspected with the ultrasound. Pictures taken with optical microscopy at the selected positions supported that signal amplitude is relatively high when the sealing area was uniform. Another reason for drop in signal amplitude is an unfavorable geometry. This could possibly be caused by the cutting unit of the packaging machine.

Seal contamination and abrasion on the seal area on the polymeric tray was detected by ultrasound (Figures 10, 11). Figure 10 shows seal discontinuities in the C-scan image. Figure

11 shows abrasion of the seal in the C-scan image. The intensity of the color and the correlation to depth/seal changes requires skill for interpretation. In general, the red in image 10 depicts the strongest portion of the seal, followed by yellow, green and then blue. The polymeric tray in Figure 10 can be said to have a weaker seal in the corner. The abrasion in the tray shown in Figure 11, is characterized by a blue streak in a uniform, green-colored portion of the tray. Color scales for each Figure are different due to a difference in sensitivity scale.

VI. PTI Air-Coupled Ultrasonic System

a. **Introduction.** In the previous section, the conventional ultrasonic technique has been described which requires immersion of the transducers and the object in water. The presence of the coupling fluid limits the applicability of this technique to laboratory use. To overcome this limitation, a number of novel approaches have been introduced in the recent years. One such approach is the air-coupled ultrasonics. Air-coupled ultrasonics relies on a new generation of ultrasonic transducers capable of generating extremely high intensity ultrasound in ambient air. These transducers are then combined with novel electronics and phase-sensitive signal processing for defect detection in a wide range of materials. Of particular relevance are the successfully demonstrated applications of this technology to milk carton seal inspection and the detection of the vacuum in meat packages. Figures 31 & 32 and are representative of a meat package with a good and bad vacuum seal.

PTI tested the feasibility of air-coupled ultrasonics to MRE packages as well as on other heat sealed joints for both off-line and on-line applications. The airborne ultrasonics appears very promising. It is noteworthy that unsealed joints, delamination, inclusions and large channel leaks (>1 mm) are easily detectable, Fig(?)

b. Basic equipment for air-coupled ultrasonic systems

- Processor:VN Instruments Ltd. NCA1000
- Transducers in through transmission: ULTRAN NCT310
  - Frequency: 800kHz
  - Bandwidth:600kHz
  - Pulse width: 50 microseconds

The principle of operation is very similar to the immersion ultrasonics, however, in this case the emitted power is much greater than the immersion system. The consequence of this is that the transducers are greater in size and lower in frequency than the immersion transducers. For this study, the through-transmission technique was used with one transducer as the emitter and another transducer as the receiver. The distance between transmitter and receiver was approximately 10 cm (4 in.)

Procedure for air-coupled testing

A sample is placed between the transmitter and receiver and the transmission intensity of ultrasound is monitored. As shown in Fig(?), a region with good seal shows higher transmitted signal than a region with little or no seal. The drop in the signal depends on the test object and the size of the disbond.

VII. Results From PTI Air-Coupled Ultrasound

PTI testesd air-coupled ultrasonic detection of MRE defects. Figure 33 is a typical result from an MRE package with a defect within the seal. A good seal was characterized by a high magnitude signal. When the ultrasound was positioned over a defect, signal strength dropped significantly. In the case where the signal was transmitted through a delaminated section, the received signal was significantly lower than even the contaminated seal.

VIII. PTI Leak Tester

a. Basic Components of LEAK TESTER (PTI FB 400). Integrity of MRE pouches was inspected using a new pressure differential technique developed at PTI. This technique is based on a three-step approach. In the first step (filling step), a vacuum is applied to a pre-set pressure after placing the flexible pouch in a closed chamber. The package is then allowed to stabilize in a pre-selected time period (equalizing step). Differential pressure was recorded during last step (testing step). Well-sealed, defect-free pouches were tested first, enabling the system to recognize good samples and to calculate reference values for filling rate, starting pressure and differential pressure. Air was introduced into a test chamber through a calibrated needle valve simulating a leak at different leak rates. A simulated leak generated values higher than reference, and dependent upon the leak rate, was accepted or rejected by the leak tester.

(1) **Chamber.** A chamber sealed with gasket around the rubber was used to seal a MRE pouch and hold the vacuum inside during testing (Figures 2, 3). This chamber is flexible so that different size MRE pouches could be tested in the same chamber.

(2) Vacuum pump. A vacuum pump was used to evacuate air and create desired level of vacuum inside the chamber.

Samples for Leak Testing

MRE (Meals-Ready to Eat) pouches were provided by Sterling Foods Inc.. Different types of MRE pouches such as oatmeal cookie, cracker and poundcake pouches were tested. Each pouch was made from the same laminated material, and several packages had been vacuum packed.

b. **Procedure for leak testing.** Each individual pouch was enclosed in the flexible chamber and test was started at predetermined conditions. A vacuum was applied to a pre-set fill pressure (900 mbar, or the pressure in the chamber at the end of the fill time. The package was allowed to stabilize and differential pressure was recorded during the last step. Well sealed, defect free pouches were tested first enabling the system to recognize good samples and to calculate reference values for filling rate, starting pressure and differential pressure. Fill rate was

described as P/T. Starting pressure is the absolute chamber pressure at the beginning of the test stage, which is normally lower than the filling pressure. Differential pressure or delta P is the chamber pressure drop from the moment test starts to the test time. Mean values, minimum and maximum readings were recorded based on total number of pouches and then system calculated the limit or reference value based on the following formula:

LIMIT = AVERAGE +/ - Sensitivity* STANDARD DEVIATION where sensitivity is the number of standard deviation to be offset from the average.

Air was introduced into test chamber through a calibrated needle valve simulating a leak at different leak rates. If a simulated leak generated values higher than the reference, it was rejected by the leak tester depending on the leak rate. If fill rate is lower than the reference, then leak can be classified as large leak. In the case where starting pressure is lower than its limit, the leak can be classified as medium leak. If leak is detected during last step where delta P is higher than its limit, then the leak is called small leak.

IX. Results from Leak Testing with PTI Leak Tester

MRE pouches were inspected for leak using PTI leak tester. Oatmeal cookie pouches were tested at different equalizing and test times. Minimum leak rate of 0.22 cc/min became detectable when equalizing and test time were 20 and 25 s respectively. However, when equalizing time decreased down to 10 s with the same testing time, minimum detectable leak rate was observed as 0.27 cc/min. When both equalizing and test times decreased down to 10 and 5 s respectively, the minimum leak rate detected was 0.73 cc/min (Figure 30).

X. ALCAN Prototype Heat Sealed Package Ultrasonic Inspection System

a. Introduction. This patented system was designed and tested by Alcan Deutschland GmbH, Ohle Works in Germany for in-line heat seal inspection of semi-rigid food packages. The in-line plant requirements placed a number of constraints on the design and this led to the development of novel transducers, special pulser/receiver units and multiplexing electronics. The final prototype has evolved from a multi-year project that began with an evaluation of potential nondestructive technologies that could be adapted to in-plant inspection. The nondestructive technologies evaluated consisted of ultrasonics, leak detection, thermography and X-radiography. The feasibility results showed that ultrasonic techniques were sensitive to seal defects of a semi-rigid aluminum laminated package of interest to ALCAN. In parallel with the laboratory tests, mathematical modeling work identified that the through-transmission ultrasonic technique in frequency range of 5 to10 MHz produce sufficient sensitivity to detect trapped food in the seal region. This was due to the special resonance condition, at that frequency range, created in the aluminum-polypropylene-aluminum laminate structure. Understanding the resonance condition was an important finding and a major step in developing a robust system for in-plant operation.

On the basis of the laboratory work conducted over 500 packages with seal defects, a system specification was developed and a mechanical scanning prototype system was constructed. This system was used to demonstrate the proof-of-concept and conduct trials at a

packaging pilot line in Germany. After ultrasonic testing, the packages were sent for incubation and subsequently manually examined by the packaging plant. The results of the ultrasonic tests and incubations were summarized in a plot that showed that for given range of response from the seal, the package would pass incubation test. This conclusion indicated that the ultrasonic technique was indeed detecting the state of the seal. At this point, because of the mechanical nature of scanning, the system was slow and the conventional transducers required water to couple ultrasonic energy to the seal area.

After this initial success, the next step was to design a system that minimized mechanical handling. This was accomplished with a semi-automatic mechanized system that relied on robots to handle the packages and the improvement in reliability proved to be significant and the cycle time of 7 seconds was achieved. This did not meet that under 1 second test cycle time per package and one option was to divert a sample of the production for ultrasonic tests. This system was making measurements at 0.7 mm steps and was capable of detecting meat fiber and gravy contamination trapped in the seal. In addition, the ultrasonic response of the seal appeared to be directly correlated with the thickness of the seal and the temperature-time-pressure history of the heat sealing process. The latter was proved to be a useful feature for heat sealing process monitoring and a nondestructive alternative to the destructive testing.

To meet the on-line requirements of package seal integrity testing, a system specification was developed and a new hardware was constructed replacing a single transducer pair in through-transmission configuration with an array of optimum transducer elements and instead of mechanical scanning, relying on electronic scanning the array, Figure 15. This system has successfully been used for testing the semi-rigid aluminum laminate package seals detecting a wide range of seal defects. In order to achieve good coverage of the seal, the ultrasonic beam spread of the discrete array elements provide more than a single coverage of the seal region. The transducer arrays were made from piezocomposite materials offering two main advantages; design flexibility and reduced reliance on fluid coupling. The use of piezocomposites permitted the manufacturer of the array to mold the array in the required shape with element sizes in the order of 2mmx0.63mm each. The second advantage was the reduced reliance on water for coupling the ultrasonic energy to the seal, although pressure and moisture are needed to provide intimate contact and optimum and consistence transmission of ultrasonic energy across the seal. The control software makes the system operation transparent to the user and at 0.2 second cycle time it exceeds the requirements for the intended packaging line. The ultrasonic sensors consists of 400 element array transmitters and 400 element array receivers bundled in 5 sets of 80 array elements and 4 sets of 100 array elements respectively. (Reference 1)

b. Basic equipment for ALCAN system

The ALCAN heat seal inspection system is a multi-channel ultrasonic testing system specially-designed to test the seal area of aluminum laminate packages using a ring-shaped transmitter/receiver transducer pair. This inspection system is controlled via an industrial PC, which is interfaced with a pulser/reciever, a multiplexer and a data acquisition and archiving system. The system is modular in design and can be readily adapted to varied inspection configurations and to in-line integration. The system is also equipped with signal processing software for real-time and in-process filtering of information at 10Mbit/sec.

(1) Ultrasonic array. For the tests conducted in this work, a special 10 elements array transmitter/10 element array receiver was used. The array was placed over the region suspected to be defective and the signals were acquired and displayed. The center frequency of the array elements is 7 MHz and the scanning cycle is approximately 200ms.

(2) Samples. Sterling Foods Inc. supplied the vacuum-packed samples with known seal defects for this test. The seal defects ranged from trapped food in the seal, short seal, foldover.

(3) **Procedure.** The seal area was place in between a pair of 10 element array elements a spray of water was introduced to the sample. After the array was manually aligned over the seal, array was triggered through the computer to capture the data, see Figure 16 showing typical test configuration.

For further technical specification of the ALCAN system, refer to Appendix IV.

XI. Results from ALCAN Ultrasonic System

Results from ultrasonic testing with the ALCAN system are shown in Figures 16-29. A special 10-element array was used for the testing of the MRE pouches. The data acquisition and software interface show the representation of the signal transmitted through a pouch. Should the seal be defect free, a uniform signal such as the signal in Figure 16 would result. Signal loss in Figure 17 is indicative of loss in seal strength. Defects such as delamination, contamination by food particles and stress cracks were easily identifiable using this system.

XII. Implementation Plan

a. Existing Situation. Sterling Foods Inc. packages baked in MRE pouches. The packages are formed using the form-fill-seal process of aluminum laminates. In this process, three side-by-side packages are sealed and later cut into individual packages that are then manually scanned for visual appearance of defective package. In compliance with the quality requirements, a sample of the production is also leak tested for the possibility of leakage.

The defects in packages can be categorized as sealing defects and foil laminate defects. Sealing defects are associated with the entrapment of foreign material in the seal and conduction sealing of laminates. Examples of the sealing defects are food in the heat seal layer, foldovers and short seals. On the other hand, examples of the foil laminate defects are pinholes and laminate coating quality.

In this project, we have demonstrated that the ultrasonic technique can detect the seal defects in the MRE packages. To achieve in-line ultrasonic inspection of MRE's, ultrasonic system must be sensitive, reliable, rapid, easy-to-integrate and robust. The robustness is defined in terms of the ability of the system to maintain its measurement integrity in harsh continuous production environment. These factors were taken into consideration in the design of the Alcan multi-element array system. Such system needs to be specially manufactured for the inspection of MRE seals. According to Sterling Foods Inc., possible options for the implementation of the

ultrasonic system are in-line and off-line. For in-line, it is suggested that the production flow and inspection should occur as follows:

1. Laminate is vacuum-formed into three cavities
2. Foodstuff is placed in the cavity
3. Upper laminate is heat-sealed to the lower web
4. Individual rows are slit
5. Each row is slit into three MRE pouches
6. Three MRE's are fed into single files
7. MRE's are held in place
8. A set of upper and lower ultrasonic arrays in contact with the seal
9. The rejected MRE is diverted
10. Accepted MRE enter a on-line visual inspection station
11. Off-line leak detection of packages to detect loss of vacuum

The steps 7 and 8 are to be integrated into the existing line. After a recent review of the production line at Sterling, it appeared that extra space for inspection was available. The time required for the added handling and the ultrasonic inspection will not slow down the process. Typically, an ultrasonic scan of the MRE seal will be complete within 200ms and the accept/reject action will be a simple diversion action that can be activated in one second or less.

XIII. Implementation Cost

a. Capital Cost

(1) Air-Coupled Ultrasound System. At the scanning frequency of 20-100Hz, the air-coupled ultrasound will be able to scan three MRE's in single row. The estimated cost of such system is approximately $250K per production line. This system is at its early development stages and no realistic cost estimates can be made for its in-line implementation.

(2) **On-line Leak Testing System.** We assume that we will use the vacuum leak detection method that requires the MRE's to be enclosed in a chamber at each production index location. This handling is complex and costly since it includes the cost of handling the MRE's and their containment arrangement, the total cost of a 12 to 15 station tester that is fully automatic can easily be between $250K to $400K.

(3) Ultrasonic array. As a rule, the total cost of an in-line ultrasonic system is 1/3 ultrasonic hardware and transducers arrays and 2/3 material handling and line integartion costs. According to a communication from the Fruanhofer Institute in Saarbrucken Germany, who have been one of the contractors for the development of the ALCAN system, a standalone ultrasonic hardware ranges from $100-$200K. This range is estimated to represent the extent of integration, signal/data processing and user-interface of the system. In addition, the arrays can cost typically in the range of $30-40K. The total cost may cost up to approximately $600-700K. The transducer cost may be reduced by reducing the number of array elements and increasing the size of the array elements. Typically, the system would use a series of active element segments in the shape of the seal region and an elastomeric layer to couple the energy to the seal and to

protect the active element. This layer is readily replaceable and although custom-made, it is not expensive. The electronics associated with the ultrasonic pulser and receiver and the data-acquisition are off-the-shelf items and require little or no maintenance as this technology is used to day in many production floors

b. Maintenance Cost. There is a cost associated with the maintenance and calibration of the system. This is an annual requirement and is no greater than the cost of maintaining other electronic measurement systems used in production lines. This cost varies from plant to plant and the actual cost estimate needs to be determined with the specific packaging plan that requires the implementation.

XIV. Summary

In this work, feasibility of using several technologies for MRE seal and package integrity was assessed. These inspection approaches were:

- Air-coupled ultrasonics
- Vacuum leak testing
- Ultrasonic Array

Based on the survey of published literature and the results of our feasibility study, we have arrived the following summary for each inspection approach.

a. Air-Coupled Ultrasonic. This new technology is useful for niche applications in which water-coupling is undesirable. Examples of such inspection are the detection of defects in paper-based laminates and inspection of package content. To inspect MRE's and other packages, this technology is still immature and there are a number of key technological hurdles to overcome such as focusing the beam to inspect small regions of the seal and the scanning of the package seal.

b. Vacuum Leak Testing. Leak testing is a prevalent technique used for determining package integrity. This technique will continue to be used both off-line and on-line. Depending on production line speed and the critical size of leak, the existing technology meets the demands of most packaging plants. Most leak testing devices need head space in the package. For less than optimum head space, leak testing may be slow and insensitive.

New leak testing techniques are reported in the literature for rapid and sensitive package inspection. It is important to note that leak testing applies stresses to the package and as such may result in failure of weak or short seals. The setup and expertise in commissioning this technology is critical to its application.

c. Ultrasonic Array. Ultrasonic array for package inspection can be used for inspecting a package seal. The main advantages of the system are its rapid response, sensitivity to seal properties and defects and adaptability to in-line use. In addition, since this system uses ultrasonic waves, it can be used to characterize the heat seal condition in terms of its thickness,

peel strength and laminate structure. In this regard, ultrasonic is a powerful tool for packaging material selection, heat sealing process evaluation and for production line commissing.

The tests with this system were successful in detecting seal defects in the MRE's supplied by Sterling Foods Inc.

Table 1 Viable Technique Characteristics

Technique	Attributes	Deficit	Detectable Defects
Leak Testing	Sensitive Not entirely non-destructive Entire package integrity	Package type Geometry/material Head space Resolution/cost	Seal, Pinhole Stress cracks
Ultrasonics	Rapid Ease of on-line use Sensitive to seal defects Heat seal characterization, thickness and peel properties	Novel technique Resolution/cost	Seal delamination Short seal Foldover Seal contamination Weak seals

Table 1 gives a view of the technique characteristics for the inspection of MRE's.

There are two types of defects that are of major concern to the MRE integrity. These are the seal defects and the pinhole or the stress crack type defects in the body of the actual package. Based on the preliminary results of this feasibility study, a 100% inspection of MRE packages can not be met with ultrasonics alone. While ultrasonic has been successful to detect MRE seal defects, this technique needs to be supplemented by leak testing to detect pinholes and stress cracks.

One possible scenario is to use ultrasonics as a nondestructive, rapid and sensitive tool to inspect package seals and can be readily adapted for in-line inspection. However, to inspect the packages for pinhole and stress cracks, the ultrasonic arrays are not suited as they require direct contact with the package and need packages to have flat and uniform surfaces. Therefore, to inspect these pouch defects, leak testing is the technique used presently at the packaging plants on the sampling basis however, as we have shown it may not be nondestructive under all circumstances. An adaptation of the leak testing technique that may not result in the weakening of the seal and over-stressing the package is required. Another important improvement that is required for leak testing technique is to increase throughput speed without affecting sensitivity.

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APPENDIX I

INSPECTION METHODS FOR SEAL INTEGRITY

Package integrity is a measure of a package's ability to keep the product in and to keep potential contaminants out (Guazzo, 1994). Adequate package integrity to assure that the product is contained within the package throughout the product shelf-life and throughout the distribution system and also to prevent the ingress of microorganisms, oxygen, filth or other environmental contaminants that could render the product unfit for consumption or which could simply reduce the quality of the product to a level less than that intended for consumption (Bourque, 1995).

The purpose of inspecting and testing flexible and semirigid containers is to ensure that the hermetic condition of the container has not been compromised. The degree of a container or seal defect may be classified by the impact the defect has on the hermetic condition. Defects are classified as critical, major and minor defect. Critical defect is a defect providing evidence that the container has lost its hermetic condition or evidence that there has been microbial growth in the container. Major defect is a defect that results in a container that does not show visible signs of having lost in hermetic condition, but the defect is of such magnitude that the container may have lost its hermetic condition. Minor defect is a defect that has no adverse effect on the hermetic condition of the container. Defect classifications and definitions are included in details in appendix I (Gavin and Weddig, 1995).

I. Evaluation of Destructive Methods

Current test methods for determining a loss of seal integrity and strength in flexible plastic pouches include destructive test methods (biotest, bubble test, dye penetration test, electrolytic, seal strength tests (burst testing and tear/tensile test), squeeze testing, trace gas sniffers, pressure change devices etc.) and visual inspection (Morris et al., 1998; Harper et al., 1995; Sizer, 1995; King, 1995; Arndt, 1992; Guazzo, 1994; Gnanasekharan and Floros, 1994). These destructive methods, if used on a statistically significant number of samples, have been used as excellent indicators of seal strength. However, they cannot be used reliably to indicate a loss in seal integrity (Harper et al., 1995).

Existing destructive methods are inadequate for indicating hard-to-see microleaks, regularly timed samplings do not indicate randomly occurring defects, and current inspection methods are very costly (Harper et al.; Marcy, 1995) and laboratory methods are often time consuming (Garrett, 1988). Another drawback of most destructive testing methods is their inability to provide information related to leak size (Gnanasekharan and Floros, 1994).

Currently, on-line visual inspection is being used to evaluate seal integrity, which imposes the limitations of both operator skill variability and human ocular resolution ($\approx 50\mu m$). It is also costly, having recently been estimated at $10,000 per million packages (Harper et al., 1995; Marcy, 1995).

Human visual inspection suffers from the predictable effects of fatigue and error. Visual examination allows for the detection of obvious defects such as misaligned seals, burnt and contaminated seals, wrinkles, delaminations, and leakers (Marcy, 1995).

II. Evaluation of Non-Destructive Methods

There is clearly a need for increased research efforts to develop 100%, on-line, non-destructive integrity testing systems to assure that every package is hermetically sealed (Bourque, 1995). The goal of 100% on-line, nondestructive testing is a worthy one, but the tool used must be appropriately validated to be reliable, repeatable, and robust for sterile products (Purohit, 1995). Research in this area is needed in two directions: first, the determination of threshold dimensions for defects; second, the development of an on-line non-destructive package integrity evaluation system (Harper et al., 1995). Non-destructive methods of package integrity evaluation should offer the advantage of 100% on-line testing and is highly desirable. Non-destructive 100% on-line inspection would ensure product safety and enable rapid detection of deviations in processing and packaging operations (Singh and Nelson, 1992).

Currently available nondestructive testing methods can be classified on the basis of operating principle as follows:

1. Optical methods
2. Acoustic methods
3. Pressure difference methods
4. Other methods

a. Optical Methods

(1) Visual Methods. Visual testing involves inspecting the seals for absence of voids, wrinkles or pleats, checking the seal alignment, and searching for product contaminated seals or delamination of packaging materials. Visual inspection is generally a gross leak detection technique with a sensitivity of 10^{-2} Pa m^3/s. This method is time consuming, expensive and its monotonous nature induces operator fatigue (Floros and Gnanasekharan, 1992).

Machine inspection is possible and practical but has inherent limitations in the ability of the sensors used to detect the types of hidden defects that can provide an entry pathway for pathogenic microorganisms (Morris et al., 1998).

(2) Machine Vision. Machine vision is the use of digital imagery for measurement, inspection, and control (Shaw et al., 1995). Machine vision has been successfully applied to 100% inspection of package seals at full production rate. Where 100% inspection is not feasible for any reason, either monitoring of the fill process or statistically significant sub-sampling may suffice. While it is still not a universal solution, machine vision has been successfully applied to the problem of package seal inspection (Roche, ?).

Machine-vision types of sensors to detect defects have limitations for the materials that are opaque or have obstructive overprinting (Morris et al., 1998) though it has been

demonstrated that star burst defects can be visualized in foil packages (Blakistone and Harper, 1995).

Shaw et al. (1995) studied three methods in machine vision for the evaluation of package seals: pixel distribution comparison, edge detection, and the Hough transform. The pixel distribution comparison method accurately classified 76% of the samples at a low resolution and 84% at a higher resolution. Edge detection correctly classified 85% of the samples. The Hough transform was evaluated as a method to measure the seal width. Machine vision can be used as a technique for detection of body and seal defects in plastic laminated foil pouch packages.

Jones and Griner (1994) developed an online system that detects seal flaws in the foil covering of rigid food containers. They categorized the defects as follows: thin seal area, wrinkles in the foil in the seal area, channels all the way through the seal area, and contaminants pressed under-neath the seal area. They found that flaws tended to have significant gradient vectors parallel to the seal area, whereas, illumination artifacts tended to have gradient vectors perpendicular to the seal area. The system was not developed beyond the prototype stage, but the results were promising for future developments of machine vision defect detection (Shaw at al., 1995).

Testing package integrity optically is an automated, and hence more rapid, form of visual inspection and can be described as computer-aided video inspection (Floros and Gnanasekharan, 1992). The use of a video camera in combination with image processing techniques have been reported as potential methods of detecting seal defects (Gagliardi et al., 1984; Wagner, 1983).

A video-based image processing system can be used to automatically inspect package seal integrity. Each seal material requires a specific lighting solution. It is difficult to inspect package seals that are translucent or partially transparent. When using reflective material, great care must be taken to avoid misleading results. Experimentation with IR, UV, and visible light has shown that visible light is the best for defining seal area (Gibson, 1995).

Video imaging applications are limited by contrast sensitivity problems and the need for characterization of all possible defects. Detection of cracks and crevices is difficult using conventional image processing equipment due to low contrast around the seal area. A special lighting technique and filters have been used to minimize this problem and effectively enhance low contrast images (Floros and Gnanasekharan, 1992).

b. Acoustic Methods. These techniques are based on the use of high frequency ultrasonic waves. Ultrasonic nondestructive testing is characterized by low power levels; hence, it is non-intrusive. Acoustic imaging and holography are widely used in medicine and they are also potentially applicable to package integrity testing (Floros and Gnanasekharan, 1992).

A variation of non-destructive testing based on low frequency acoustic principle is limited to the tap tests that use an electromagnetic probe to create a audible tone whose pitch varies with the level of pressure/vacuum in the package. The classic tap test that characterizes

materials based on their acoustic resonance was described. A composite material with good bonding between its various layers can be excited by an ultrasonic pulse, and it resonates with a specific frequency. In principle, when some degree of delamination is present in the same material, its resonant frequency is altered. This forms the basis of an ultrasonic detection of seal integrity (Gnanasekharan and Floros, 1994).

Ultrasonic techniques have been widely used in many scientific areas. In food industry, their applicability to quality control of both fresh and processed foodstuff has also been studied. The stability of reconstituted orange juice, the skin texture of oranges, cracks in tomatoes and defects in husked sweetcorn have been investigated with ultrasonics. Ultrasonic measurements have been employed to detect microbial spoilage in aseptically packed milk products through various packaging materials. Ultrasound images of milk products were digitalised and the numerical values of images correlated very well with the bacterial counts (Ahvenainen et al., 1989). Ahvenainen et al. (1989) also studied the detection of microbial spoilage of various packaged foods such as ice cream, tomato sauce and pea soup using ultrasonic imaging.

Other application in food industry is for non-destructive measurements of the thickness of eggshells (Gould, 1972). The speed of transmission of ultrasound pulses through fats and oils has been also studied in estimating their solid/liquid ratios (Miles et al., 1985).

Prior tests of the non-contact acoustic technology indicated that it has the ability to detect fill level and differentiate between containers that have vacuum (seal) and those that do not (leaker) (Rodriguez, 1995).

The preliminary study done by Morris et al. (1998) showed that acoustic imaging can nondestructively image micrometer-scale defects as well as any sort of inclusions in the seal area in the heat seals irrespective to their optical properties. It was indicated that a 10μm channel defect was detected using a SLAM (Scanning Laser Acoustic Microscopy) with a 20μm resolution. However, a 10μm channel defect could not be measured with useful accuracy. Higher frequency acoustic microscope technique should be used in order to characterize channel defects in the 10μm diameter range. Ultrasound systems such as SLAM require medium, such as water, through which the sound waves are transmitted and then measured by vibrometer (Blakistone and Harper, 1995). The on-line implementation of a SLAM based method seems impractical since the equipment is cumbersome and expensive (Morris et al., 1998).

Current study was done by Ozguler et al. (1998) using ultrasonic imaging to detect micro-leaks and seal contamination in flexible food packages by the pulse-echo technique. The results of this study showed that 17.3-MHz pulse-echo Backscattered Amplitude Integral (BAI)-imaging detected channel defects (9.5-15μm) and all simulated food strand inclusion defects in both types of plastic and foil containing retortable pouches.

Acoustic imaging is one of the better alternatives for the development of a sensor that would provide the needed sensitivity, spatial and temporary resolution (Morris et al., 1998).

c. Pressure Difference Methods. Non-destructive package integrity testing currently is based on the pressure difference methods. Pressure difference methods is categorized into pressure or vacuum decay methods and trace gas detection methods. Pressure or vacuum decay methods involve monitoring of a pressured or vacuumed in a system for pressure changes at regular time intervals. For empty or open containers the test is conducted by either filling the package with fluid (gas or air) or evacuating it to preset degree and measuring pressure changes with a suitable pressure sensor. For filled and sealed packages test can be conducted by incorporating a control volume into the circuit and directly measuring differential pressure induced movement (deflection) of package components. Trace gas detection involves analytical determination of the presence or absence of a preselected trace gas in a package. The trace gas or tracer can be naturally present in the headspace or be introduced into it. Commonly employed tracers are oxygen, carbon dioxide, water vapor, nitrogen and helium. Infrared detectors, gas chromatographs and mass spectrometers are popular detection systems. Trace gas detection is the most sensitive method currently available with a maximum sensitivity of 10^{-12} Pa m^3/s for helium detection using a mass spectrometer (Floros and Gnanasekharan, 1992). The helium test was also used to identify pinholes on flexible retort pouches; but this test was destructive (Gilchrist et al., 1989).

d. Other Methods

(1) X-Ray. X-ray systems have so far not been able to demonstrate the ability to find an unfilled leak with any useful resolution due to the lack of differential in density between a whole seal and two unsealed but adjacent pieces of material (Morris et al., 1998). X ray will detect a 1 μm drop of water in the seal area but will not detect 1 μm channel leak because it cannot detect voids unless there is something in them (Blakistone and Harper, 1995).

(2) Infrared Scanning. Lampi et al. (1973) described a non-destructive seal-defect-detection method that uses infrared radiometric scanning of heated seal surfaces. In this technique, the heat source and the detector are stationary, while the pouch seal area is passed between them at up to 15 cm per sec. In principle, defects in the seal area should impede heat flow sufficiently so that the detector can measure the temperature drop. A prototype machine to scan seals and reject defective ones has been constructed and proven feasible and reliable, but its cost is high ((Lampi et al., 1976).

The infrared scanner is technically applicable for detecting seal defects at speeds at least up to 6 inches of seal per second. Its pragmatic applicability depends on three points: (1) effectiveness of measures to eliminate concern over seal contamination, (2) definition of defects and establishment of acceptance/rejection criteria, and (3) justification of its relatively high cost (Lampi, 1977).

(3) Testing of Aseptic Packages. There are three commonly used destructive tests that provide information on container integrity: (1) Teardown, (2) Electrolytic test, and (3) Dye test. However, the ideal test for a package would be a machine, which could detect untight or unsterile packages without opening the package. There are two instruments to perform such functions. The first is an instrument, which continuously scans the package profile as they pass by on the conveyor. If the package leaks, then air entering the package should result in a change,

which can be picked up by the scanner. This is similar to dud detectors used by the canning industry. However, with aseptic packages, the profile scanners are not effective because the package defect usually does not immediately change the package profile. The second instrument, the Valio Electester, can detect unsterile packages after they have been incubated for 7 days. The instrument senses difference in rotational inertia caused by the viscosity changes in the product. This instrument is applicable only to products which undergo a viscosity change when they spoil and requires a 7 day incubation followed by testing of each individual package (Sizer, 1983).

III. Evaluation of Defects for Seal Integrity

Further work needs to be done in order to evaluate which seal defects could lead to a compromise in package integrity and to develop defect identification guidelines. Once these criteria are established, then equipment manufacturers can calibrate inspection systems (Harper et al., 1995).

NFPA (National Food Processor Association) established uniform defect definitions and their classification. All defects were classified according to package type (paperboard packages, flexible pouches, plastic packages with heat-sealed lids and plastic packages with double-seamed metal ends) since different types of packages require different defect definitions and test procedures. Each defect was also assigned to one of the three categories: critical defect, major and minor defects (Denny, 1989; Gavin and Weddig, 1995; Marcy, 1995; Sizer, 1995). Requirements for plastic package integrity testing in the military are included in Military Specifications (Marsh, 1995). MIL-P-44073D (1992) specifies testing procedures for the MRE. MIL-STD-105E (1993) presents guidelines for the number of random samples required for testing a given lot size at a specified inspection level and offers the performance of those samples required to pass Acceptable Quality Level. The classification and the definitions of seal defects for flexible pouches and plastic packages (or semi-rigid containers) with heat sealed lids, which are the concern for this project were included in appendix II. The definition and requirements for a good seal have been subjective and somewhat nebulous. Each authority has had, to some extent, its own vocabulary and performance indicators (Lampi et al., 1976).

APPENDIX II.

Classifications and Definitions of SEAL DEFECTS by NFPA Bulletin (Marcy, 1995)
Main Classification of Defects

- "Critical" Defects - When loss of integrity is apparent
- "Major" Defects - When loss of integrity is suspected
- "Minor" Defects When not having any adverse effect on integrity

Defect Classification for heat seal closures (flexible and semirigid containers)
Seal delamination

Channel leaker: *"a patch of nonbonding across the width of the seal creating a leak"*

Incomplete seal: *"a portion of the seal that has a lack of adhesion between lid and body"*
Seal contamination

Contaminated seals: *"foreign matter in the seal area such as water, grease or food"*

Blister: *"a void within the bonded seal"*
Seal deformation

Wrinkles: *"a fold of material in the seal area"*

Convolutions: *"a slight visual impression in the seal indented on one side and raised on the other side"*

Table 1. Classification of seal defects associated with flexible pouches

Defect	Critical	Major	Minor
Blister	-	+	+
Burning	-	+	+
Channel leaker	+	-	-
Contamination	-	+	+
Convolution	-	-	+
Crooked seal/short seal	+	-	+
Flex cracks/seal cracking	+	-	+
Heat ripples	-	-	+
Hot fold	-	-	+
Marks on seal	-	-	+
Non-bonding	+	-	-
Seal creep	-	+	+
Uneven seal juncture	-	-	+
Wrinkle	+	+	+

Four main group of packages that cause similar integrity concerns: (Gavin and Weddig, 1995)

Flexible pouches
Plastic cups and trays with flexible lids (or semi-rigid containers with heat sealed lids)
Plastic cans with double-seamed metal ends
Paperboard packages

Definitions of Seal Defects associated with flexible pouches

Blister: A void within the bonded seal. This defect will appear to resemble a bubble in the sealed area. On a foil pouch, the blister will cause a raised appearance on the seal.

Burning: A milky white appearance on the seal is an indication of excess heat/pressure. Some appear as delamination or small blisters on the seal, caused by incorrect heat, pressure or dwell time.

Channel leaker: A patch of non-bonded area across the width of the seal creating a leak. This defect can sometimes be detected visually by the absence of a portion of the seal impression in a seal. If a pouch has a channel leaker, it will usually be detected by applying pressure toward the seal.

Contamination: Foreign matters in the seal area such as, but not limited to, water, grease or food. A pouch with contamination will have a noticeable raised area in the seal where the seal bar has sealed over the contamination. The condition is acceptable if there is a minimum clear seal width of 3/32-inch.

Convolution: A slight visual impression in the seal indented on one side and raised on the other.

Crooked seal/short seal: A seal that is not parallel to the cut edge of the pouch. A hermetic seal that is on an angle with any amount of unsealed material above the closure seal is acceptable. If the seal is on the edge of the pouch with a narrowing on one end, it is acceptable as long as the width is a minimum of 3/32-inch.

Flex cracks/seal cracking: Small breaks in one or more layers of package, due to flexing, but not a leaker. Will appear as a deep, rough textured wrinkle on a pouch. Cracking in the sea area may not be adjacent to the inner seal and light may not pass through.

Heat ripples: Thin, multiple ripples on a seal caused by heat/tension. Ripples are on the two-outer layers and do not affect the inner layer or seal integrity.

Hot fold: A permanent bend in a seal formed after sealing but before the seal area has cooled. This may appear as a large wrinkle or a fold that has been sealed over.

Marks on seal: Flat, unraised marks appearing on one or both sides of a pouch seal. Common causes are plastic build-up on the seal die, a dirty die, or a nick in the die.

Non-bonding: Failure of two sealant films to combine during the sealing process. This can be detected visually by the sealing bar impression on a pouch. If it is in only one area, there will be

a faint void in the seal. If it is in the whole seal, the seal impression will be very faint. Applying pressure to the seal area will cause the seal to separate.

Seal creep: Partial opening of the inner border of the seal. This problem normally detected by applying some pressure upward toward the seal.

Uneven seal juncture: Wavy or rough appearance of bonded polymer at the seal juncture. This will appear as small wrinkles but not the fold-over type. The inner seal juncture may also have a wavy appearance.

Wrinkle: A fold of material in the seal area. This problem is highly visual, since the seal will have a pleated appearance from the foldover of the pouch material and can be seen on the unsealed area above the seal. Unacceptable conditions are foldover wrinkles and deep multiple wrinkles. Single deep wrinkle or flat wrinkles are to be tested for acceptability.

Table 2. Classification of seal defects associated with semi-rigid containers with heat sealed lids

Defect	Critical	Major	Minor
Burnt seal	-	-	+
Channel leaker	+	-	-
Contaminated seal	-	+	-
Incomplete seal	+	-	-
Seal with variation	-	+	-
Uneven impression	-	+	-
Wrinkle	+	+	+

Definitions of Seal Defects associated with semi-rigid containers with heat sealed lids

Burnt seal: A discolored area of the seal due to over-heating.

Channel leaker: A patch of non-bonded area across the width of the seal creating a leak.

Contaminated seal: Foreign matters in the seal area such as, but not limited to, water, grease or food.

Incomplete seal: A portion of the seal that has a lack of adhesion between lid and body.

Seal with variation: Less than specified seal width.

Uneven impression: One that may lead to an out-of specification seal.

Wrinkle: A fold of material in the sealed area.

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APPENDIX III.

Quarterly Progress Report EWI **11-11-98**

The objective of the project EWI-42409CSP is to determine the feasibility of implementing an integrated, in-line system for ultrasonic seal integrity inspection of Sterling Foods Pouches. Three tasks have been established for completing the feasibility study.

Task 1-Literature and Equipment Supplier Search was intended for determining state-of-the-art in the correlation between the ultrasonic response of the packaging laminate and the relevant material properties. A review of the use of ultrasonics in the industry and the application of ultrasonics as well as other technologies, and the inspection of laminates and food packages were assessed. Standard and custom commercially available units and custom integrated industrial systems were assessed and their relevance was classified.

Sterling Foods identified and sent several types of defects to OSU/EWI for analysis and identification. A preliminary assessment of defects by OSU indicated that initially, EWI would determine the feasibility of ultrasonics for seal defect detection. EWI began a survey of package inspection technologies and identified manufacturers of the technology.

Task 2 – Preliminary Ultrasonic Evaluation and Defect Characterization of Seals, was intended for the procurement of samples from Sterling and EWI-based laboratory experiments on the samples. The samples were to have known defects for a number of ultrasonic parameters would be monitored and a comparison with the defects was to be made.

Sterling Foods was visited in mid-August for assembly-line analysis for future implementation sites. The packaging line at Sterling was intently studied so as to gain better understanding of the process. Several important factors evolved from this visit, pertaining to the in-line system specification intended for Task 3. Analysis of defects was done at EWI whilst Sterling continued to provide more samples. Recently a series of representative defective MRE samples were supplied by Sterling that has been used for technique evaluation.

A visit to U.S. Army Natick was made in early October for introduction of EWI associates involved in the process and for requested input from U.S. Army Natick associates. A tour of the facility was given and the capabilities of Natick were demonstrated. Natick provided some useful comments on their experience with MRE integrity and expressed their interest in the outcome of the project.

PTI-Packaging Technologies and Inspection was visited in late August and November. After the visit, EWI decided to collaborate with PTI due to their extensive capabilities and experience in packaging defect recognition. A week worth of intensive tests has been performed at PTI by OSU and EWI. Using PTI's equipment and expertise, several methods of seal integrity detection were tested on samples provided by Sterling. These included air-coupled ultrasound, leak tests

and ALCAN prototypical ultrasonic technology. PTI will also conduct the base-line evaluation of the potential techniques for inspection of the MRE seal and package defects.

Task 3- In-Line System Specification is intended for a plant system specification to be prepared. This spec will involve the associates form Sterling, OSU and EWI for determining operating parameters such as line speed, package handling and operator interface.

Review of Technology Providers and Commercial Inspection Systems

PTI

Packaging Technologies and Inspection develops, manufactures & distributes non-destructive high precision leak detection systems for pouches, packages, container, components, vials, ampoules, medical devices, oil and fuel filters, offering real time quality & process control . PTI integrates machine vision systems, ultrasonics & label inspection systems.

Taptone

Taptone has developed a microprocessor-based system to detect defects non-destructively. These systems were developed for on-line inspection for single file containers at speed. Several different models have been developed using a variety of different techniques for inspection. The high detection speed is attained by the use of digital signal processing, which also allows for Statistical Process Control of the measured parameter. According to Taptone, the following system configuration offers a range solutions to inspect specific package types, such as rigid containers.

- *Taptone II* uses a magnetically induced acoustic response to determine vacuum or pressure levels within the container. Speed of up to 2000cpm is attainable.

- *Case Taptone II* is a variation of Taptone II in that it uses the same detection technology. However, it can inspect the containers, after incubation or warehousing, after they have been packaged and sealed in cases. Speeds of up to 2000cpm are attainable.

- *Turbo Trak* uses ultrasonic transducers to detect lid curvature to analyze internal atmosphere and seal integrity. It allows for different parameter setting for different containers on the same line. Speeds of up to 200 cases/m are attainable.

- *Tracker* uses ultrasonic transducers to discriminate insufficient pressure or vacuum on line, by detecting lid curvature of the containers. Speed of up to 2000cpm is attainable.

- *Laser Turbo Trak* provides inspection of containers with metallic and plastic enclosures using laser technology. The laser sensors determine lid shape and assign a pass/fail status to the container. This system is capable of measuring 1200 cpm.

NEWCO

NEWCO literature indicates the range of nondestructive methods available for material testing and characterization.

- *Ultrasonic* Inspection is available in hand-held and dedicated units using Panametrics equipment. These systems are capable of detecting flaws within the material.
- *X-Ray* Inspection is available for real-time analysis of packages. These systems make use of Digital Signal Processing to minimize inspection algorithm time.
- *Magnetic Particle* Systems are available in both automatic and portable systems. These systems use Magnaflux technology.
- *Liquid Penetrant* systems are available with make use of Magnaflux technology.
- *Eddy Current* systems are fully automatic for surface and sub-surface inspection of ferrous and non-ferrous metals and engineering components.
- *Infrared inspection* systems are available with a variety of cameras and detection capabilities. Image processing software relies on DSP for maximum efficiency.
- *Visual Inspection Systems* are available making of use of DSP for on-line measurement of products.
- *Leak Detection Systems* are also available using vacuum devices.

AutoRoll

Autovision develops visual Inspection Systems for on-line inspection of various parameters. They are used mainly in the pharmaceutical industry for bar code/ label inspection and color discrimination of products. These systems operate at high rates of speed, but are generally for label detection/analyzing rather than package integrity.

Qualitek

Qualitek's 621 Air Pressure Decay Leak Tester is an on-line leak detection system. The technology used is a pressure transducer that measures both test pressure and leak rate. These systems can be used on food packages.

Cognex

Cognex is a visual inspection system developer for customized system. They make use of DSP technology to develop non-destructive, high speed, on-line systems for measurement of a variety of defects and parameters.
Software is developed by Cognex specific to every application. They have inspected small surface-mount PCB components to large machine components. Their technology has been implemented by food packaging production lines to inspect package seal after filling and prior to sealing.

ALPS

Alps LeakINSPECTORS have several products designed for in-line, automatic leak detection and off-line manual leak detection. The technology incorporates pressure sensors to determine such defects as excessive and minimum stretch, leak and gross leak, and overfill. These systems test non-destructively, using a separate rotary conveyer, which deposits the container back to the main processing line.

Shibuya

Shibuya offers both a 100% on-line inspection system and an off-line bench tester. Both systems utilize non-destructive testing by means of a vacuum and differential pressure sensors. The sensor is used to detect gas leakage from within the container. The system can be fully automatic and inspects packages such as flexible containers, pouches and aseptic products. Another system offered is the Pinhole Inspector, which used differential pressure sensors to detect pinhole defects in the sealing area of filled and capped containers. All systems use an infeed conveyer and can operate at high rates of speed.

Advanced Technologies

Spectrum vision inspection systems are completely non-destructive on-line systems. They rely solely on machine vision for inspection of pharmaceutical packages, automotive components and food products. Both color and monochrome units are available with the ability to adjust sensitivity and tolerance per product type. They claim an inspection speed of up to 3,600 ppm for 100% inspection. On pouches similar to MRE, the Spectrum system uses white lighting and proprietary light shaping diffusers for ideal illumination.

RICO

Rico manufactures a precision leak detector for either pressure or vacuum leaks down to 0.10cc/min. These systems measure the actual flow rate of gas escaping form the leak. They specialize in industrial leak detection and aircraft instrumentation applications.

GSMA-Parish Automation

Parish specializes in high-accuracy robotic vision systems for 100% inspection. The RoboSpect is a label verification system, PageSpect is an inspection system for pin-fed and roll-fed labels;

Inspect is a counting system for tablets, cartons, etc.; and RoboPharm is a robotic inspection and case packing system inclusive.

DVT

DVT manufactures high-speed on-line inspection systems for relatively low cost. Their patented SmartImage sensor technology benefits such fields as automotive, packaging, pharmaceutical and electronics to name a few.

T. M. Electronics

T.M. Electronics manufactures instrumentation for seal strength testing and leak testing of medical devices. Both manual and automated testers are manufactured with potential applications in packaging industry.

Vision Components

VC manufactures intelligent camera systems combining a CCD camera and processing hardware in one package. These systems are relatively inexpensive and offer a complete vision system in itself. The output of these devices is video, RS485 or PLC.

TDX-Thermetics Detection Inc.

TDX produces a digital X-ray imaging system that recognizes fill level, fill volume and net content of containers or packages on a filling line. Data is captured horizontally and vertically producing a picture of the container. Multiple decisions about the robustness/integrity of the package are made before the final pass-fail, making this system uniquely intelligent.

AGR International Inc.

AGR manufactures a conveyor vision inspection system (CVIS), using Aquity vision system, specifically for plastic containers on a table top conveyor system. The base, sidewall and /or neck regions of the container can be inspected. Speeds of up to 150 containers per minute are attainable at 100% automated inspection.

Papers/Technical Reports/Articles

Production Quality Control Problems Ref. 1

This paper concentrates on many facets of automated inspection using machine vision and imaging. It highlights the problems likely to be encountered when inspecting shelf stable packages. These include lighting or illumination, speed of packages on conveyor, distinguishable defect size and reflectivity of seal material. This paper does not address solutions but rather forms a checklist for difficulties that most probably will be encountered.

Development of Vision system for Flexible packaging of random shapes Ref. 2

The aim of the technology documented in this paper is the determination of what type of package to provide to randomly shaped goods. The paper uses a vision approach to determine fit-up for packaging. No seal integrity is discussed, but what is viable is the use of machine vision in an automated fashion. Software characteristics are discussed along with results of testing.

Machine Vision Inspection of Heat Seals at Full Line Speeds Ref. 3

This paper discussed the many aspects that can alter a package seal. Machine vision as a means to detect seal integrity both before the sealing and after is discussed. Several defects are said to be detected at full line speeds. These defects include channel leaks, insufficient seal width, improperly sealed areas or holes in the sealing web. A general guideline for plant implementation is noted.

Perfectseal Develops Web-Inspection System Ref. 4

This paper discussed the development of Perfecseal's own web inspection system for their packaging coatings. The system is based on a single-point laser that scans the web for imperfection. The scanning provides a "defect map" where the flaw can be easily recognized.

Yarn Package Inspection with Computer Vision and Robotics Ref. 5

The vision system developed for yarn package inspection at the North Carolina State University used both machine vision and robotics for detection of certain flaws in packages. The flaws detectable were those relating to overall size of package, malformation and package centering. Flaws detection proven to be less effective than human inspection are those defects relating to the structure of the yarn within the package and debris/discoloration on the package itself.

Machine Vision for Foil Package Defect Detection **Ref**. 6

This paper discussed the use of machine vision for the inspection of foil packages. The areas of analysis included: Seal integrity, where contaminants in the seal were the area of concern, seal width, and package body integrity, where defects inside the sealed area are of concentration. Other types of detection methods were suggested including; Color imaging-to detect the difference in color due to leaking fluid, Infrared Imaging- spectral and thermal characteristics will be analyzed for seal integrity, and X-ray imaging.

Locate That Leak Ref 7

This paper gives a brief overview of the types of systems available for leak detection. It describes each process and gives guidelines as to which process should be used for what size leak. The technologies covered include pressure decay systems, mass flow systems, mass spectrometry with hard volume, bubble/dunk tank tests, halogen tracer gas and ultrasonic detectors.

a. **New Sensors Help Improve Heat-seal Microleak Detection** Ref. 8

This paper gives a brief overview on the technologies currently used for the inspection of flaws within a flexible package. It describes the problems that certain technology face with flexible packages and describes what size and type of defect would likely be imaged with each

technique. The concentration of the paper is to determine defects in the micrometer range generally classified as wrinkle inclusion of foreign materials, and post-sealing damage. Machine vision, X-ray, MRI and acoustic imaging techniques are all discussed with a greatest emphasis on the acoustic imaging or acoustic microscopy. Preliminary results of the study suggest that detecting microleaks in flexible packages would best be performed with acoustic imaging technologies. The aim of this work is not towards on-line implementation of packages

Industrial Use of Real-Time Optical Inspection System Ref. 9

This paper discusses the use of Fourier and Hough transforms can be used in industrial inspection application. Real-time optical transform inspection is discussed and several real-world examples are presented and discussed. Any potential applications in packaging

Inspection Systems Ref. 10

This paper discussed the use of the OpticScan 4™ system for the inspection of milk bottles. The system works on the principles of optics and utilized four overlapping scans of the inside of the bottle. The system is complete in that is provides complete bottle handling from beginning of inspection through reject or acceptance. It also includes infrared sensors for detecting residual liquid in the bottle prior to inspection.

Detection of Container Faults In-Line Ref. 11

The purpose of this paper was to give a brief review of inspection technologies and fault detection systems. It discusses the types of container faults that are most prevalent and discussed forms of non-destructive technologies applicable to each. Not only does it list the advantages, but also the limitation of each type of technology. Mass spectrometry, tracer gas, helium leak testing, laser optical dimensioning systems, real time X-rays, thermal imaging and electromagnetic induction are all discussed.

Pressure Differential Techniques for Package Integrity Inspection Ref. 12

This paper describes the two main defects of military MRE's and a way to non-destructively inspect them using an application of pressure differential techniques. Previous work on NDE techniques for MRE's are documented, such as burst test, tensile test, visual examination, dye penetrant and bond strength tests. A case of open/empty package and a case of a closed/sealed package are discussed along with results of initial tests using the pressure differential technique.

Integrity of Food Packages Ref. 13

This paper is an early paper on using flexible packages for MRE's. The paper considers the effects of holes or leaks in the pouches and discusses what criteria should be considered upon the change from metal cans to flexible pouches. No mention of testing or NDE inspection is mentioned, yet it gives a good background as to the research that went into the switch from metal can to flexible package.

Feasibility of Using a Non-destructive Ultrasonic Technique for Detecting Defective Seals Ref. 14

This paper describes an NDE technique for the detection of defects in flexible packages. Distinguishable defects included wrinkles, voids, food particles and moisture. This technique

proved amenable to on-line inspection, although it was only tested off-line. Another important factor found was a correlation between ultrasonic velocity and contamination level.

Study of Leak Detection of Fluids Ref. 15

This paper gives an in-depth view of what the typical limitations of bubble-test solutions are. Generally, the solutions can only react to a leak above 10-4 std cm3/s. With certain additives, a solution can be generated that can allow for detection of leaks at significantly lower levels. The paper discusses the experimental method of finding such a solution, the conventional and beneficial additives and the results.

Inspects Package Seals Ref. 16

This paper details an experiment using infrared sensing of flexible food pouch seals. The system first heats the underside of the seal with a beam of focused radiation; next a radiometer measures the temp of the top side; last, the data is analyzed and the package is either accepted or rejected. The system is capable of inspecting a 0.25 inch band along the seal, and the defects detectable are food particles, grease, moisture, air bubbles, and wrinkles at a rate of 60 packages per minute.

Ultrasonic Echography- A Nondestructive Method For Quality Control of Packed UHT Milk Ref. 17

This paper describes a test of using the NDE technique of ultrasonic echography to determine the amount of bacteria present in milk containers of plastic bottles or bags. The milk was inoculated with a certain bacteria in varying amounts. The milk was echographed daily for 5 days and results indicated that the technique could be used to detect the changes in mile composition due to the bacteria.

The Effectiveness of the United Nations' Leakproofness Tests Ref. 18

This paper details the tests required for packages of dangerous goods. The tests include submerging the package into water and then over-pressuring the package. The author explains that the tests are not valid because the orientation of the package while submerged is unspecified. At certain angles the test pressure of the package would not be accurate due to the water pressure working against the pressure of the package. The second criterion involves the use of over pressuring, in that the UN tests procedures do not specify any certain length of time. The expansion of a gas bubble in a liquid is discussed physically and the outflow of liquid through a pinhole is used as an example.

Leak Detection On-Line and On Time Ref. 19

This paper discusses the use of 100%, on-line inspection of packages. The benefits such as cost saving and SPC are documented with real-world examples. Several existing machine types are mentioned for on-line inspection, each with a specific niche. Plastic bottles and pouches, vacuum brick packs and case-inspection are some of the products that can be on-line inspected by NDE.

Package Integrity Evaluation: Criteria for Selecting a Method Ref. 20

This paper discusses previously used tests for package integrity and then improvements upon these techniques to present day techniques. Methods of integrity evaluation both

destructively and non-destructively, are addressed. Electrolytic, dye penetrant and bubble tests are discussed along with their advantages and disadvantages. NDE techniques such as pressure difference, vacuum, ultrasonic imaging and holography, force field sensing and laser interferometry are discussed.

Automated Non-Destructive Package Integrity Testing Ref. 21

This paper gives an extensive review of some nondestructive evaluation methods for package integrity that are amenable to automation. Pressure difference testing was explained in detail, along with its applications. Optical methods, acoustic methods, pressure difference methods and thermography are briefly discussed.

Determination of Small leaks in Large Pressurized Volumes Ref. 22

This paper discussed the use of two methods of pressurized gas leak detection; Pressure decay method and Mass replacement method. The limitations of each are discussed.

On-Line Inspection System Assures 100% Foreign Particle Free Packages Ref. 23

This paper introduces a product named the Model 1000, which is an upgraded version of a 1974 Model inspection system. This system is based on x-ray imaging and a television camera to capture the image. This electronic system can automatically inspect food, beverage or pharmaceutical products at speeds up to 420 per minute. The system consists of two station; an inspection station and a reject station. The machine is automatically forgiving of changes caused by container shape.

Aseptic Integrity and Microhole Determination of Packages by Gas Leakage Detection Ref. 24

This paper documents the use of two technologies for micro-leak detection. Infrared Spectrometry is discussed in detail and its limitations, such as long testing time (0.5" to 0.5 hour) are documented. The use of a Mass Spectrometer is also introduced along with its limitations, such as the need to use different aperture per hole size. The two methods of transmission of gases & vapors through packages: leakage and permeation are briefly discussed.

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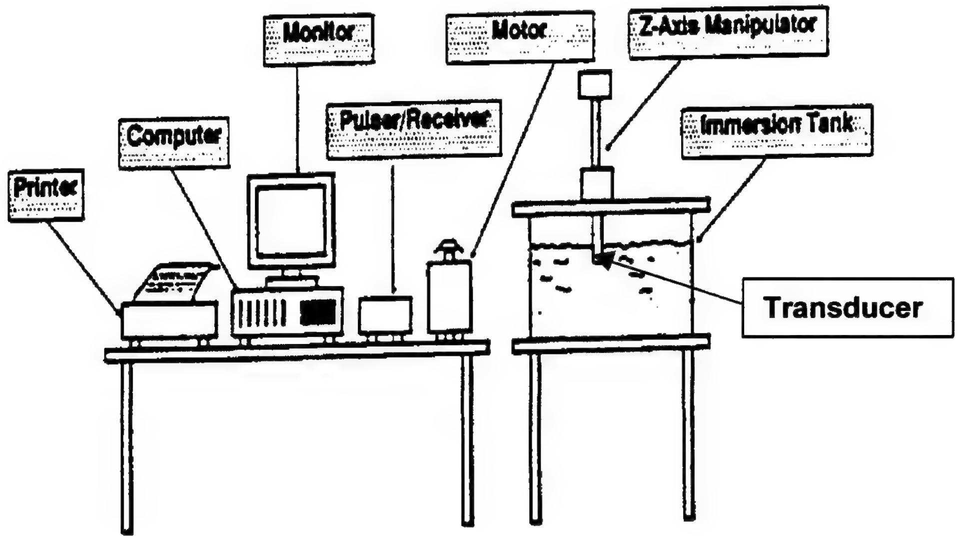

Figure 1. **Basic Components of Ultrasonic Instrument**

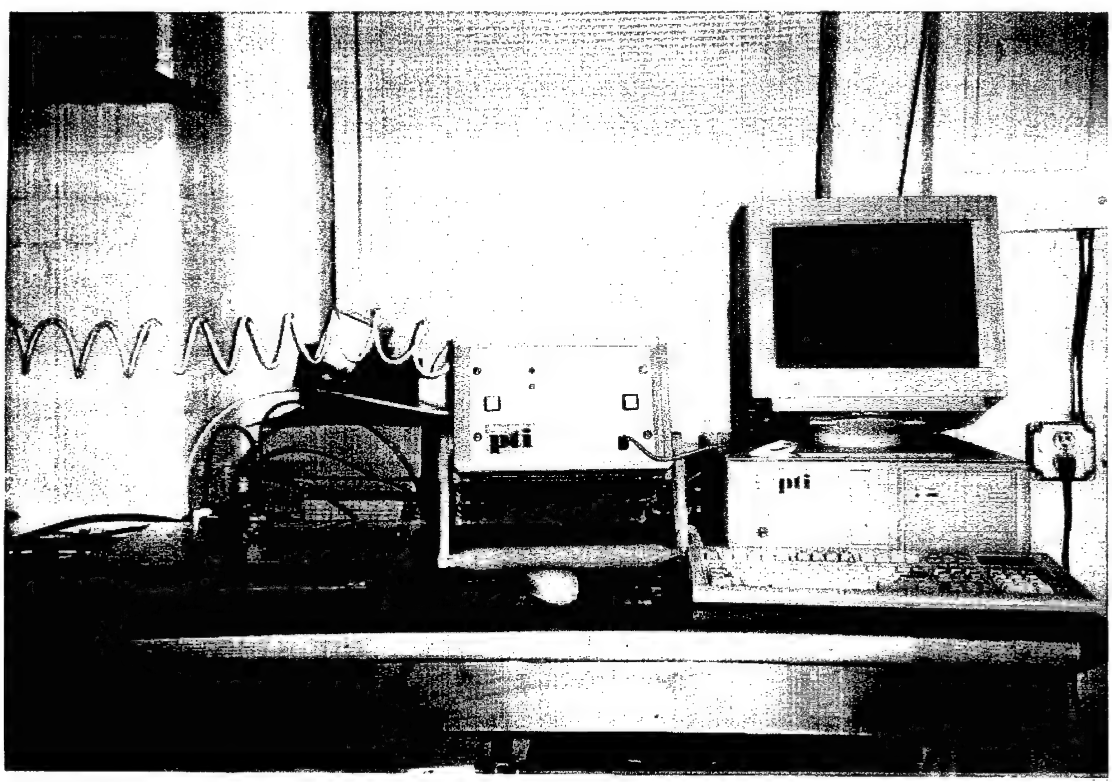

Figure 2. **Basic components of PTI leak tester**

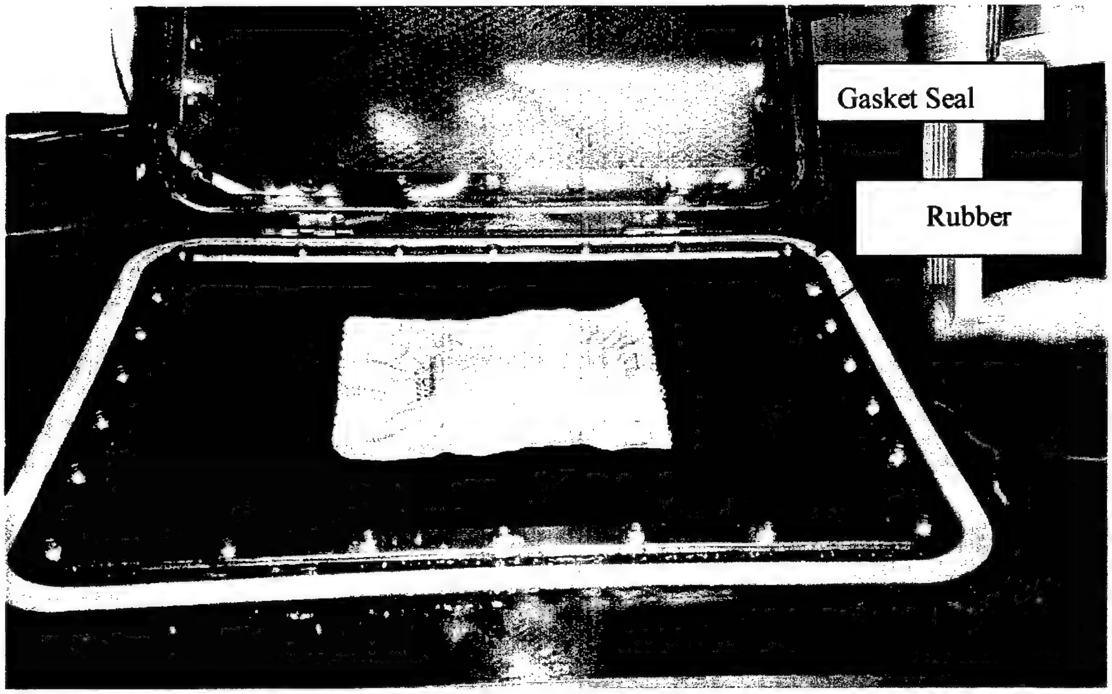

Figure 3. **Chamber**

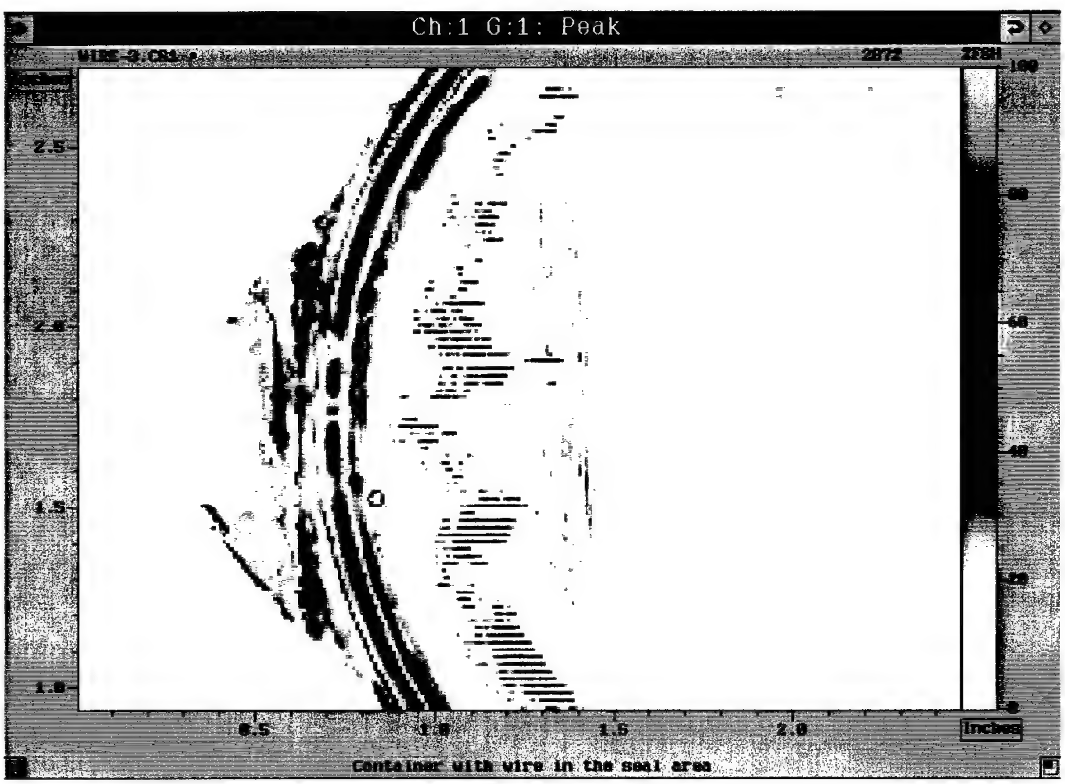

Figure 4. **Partial C-scan imaging of a semi-rigid cup with wire in the seal area**

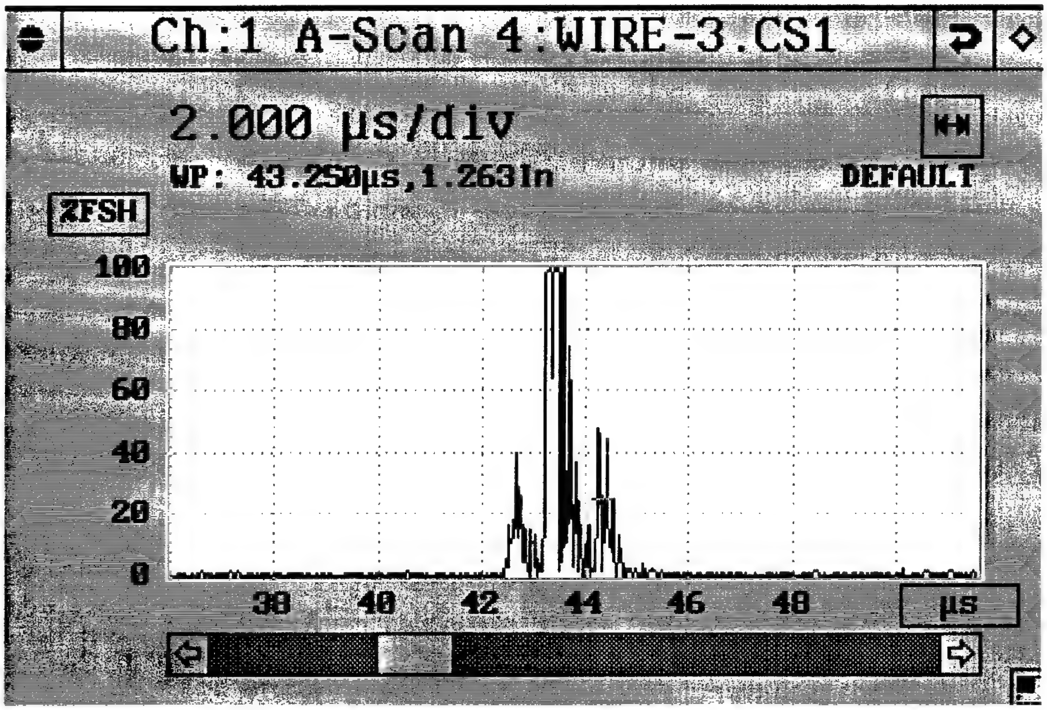

Figure 5. **A-scan presentation of a semi-rigid cup with wire in the seal (waveform of position A, reference signal at undisturbed seal region)**

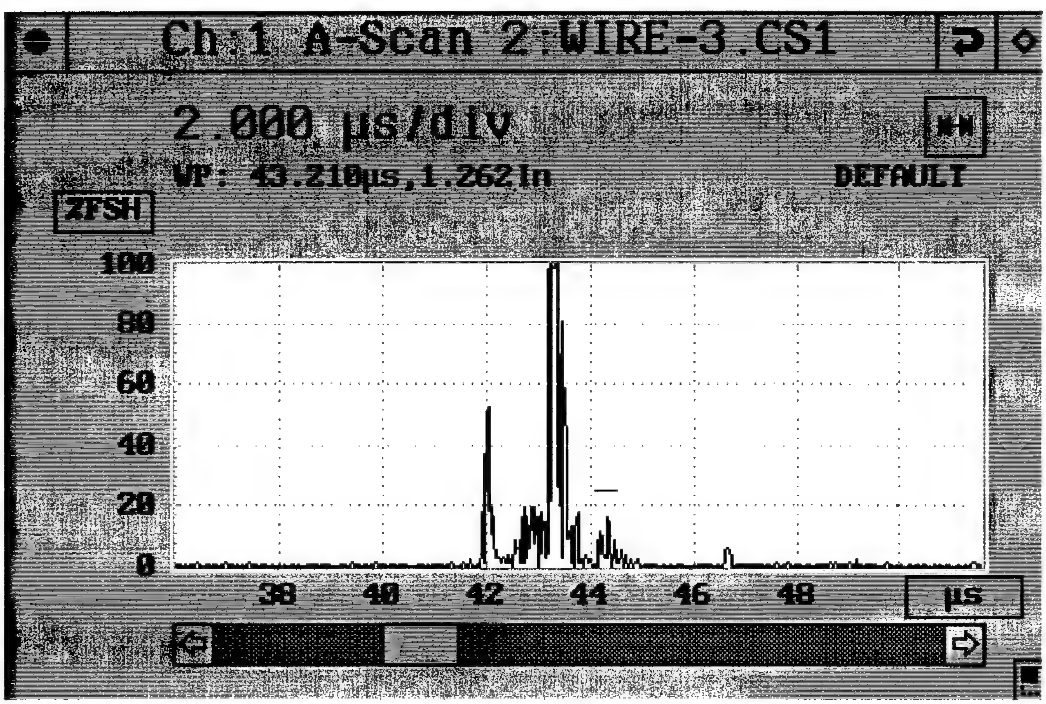

Figure 6. **A-scan presentation of a semi-rigid cup with wire in the seal (waveform of position B, disturbed seal region)**

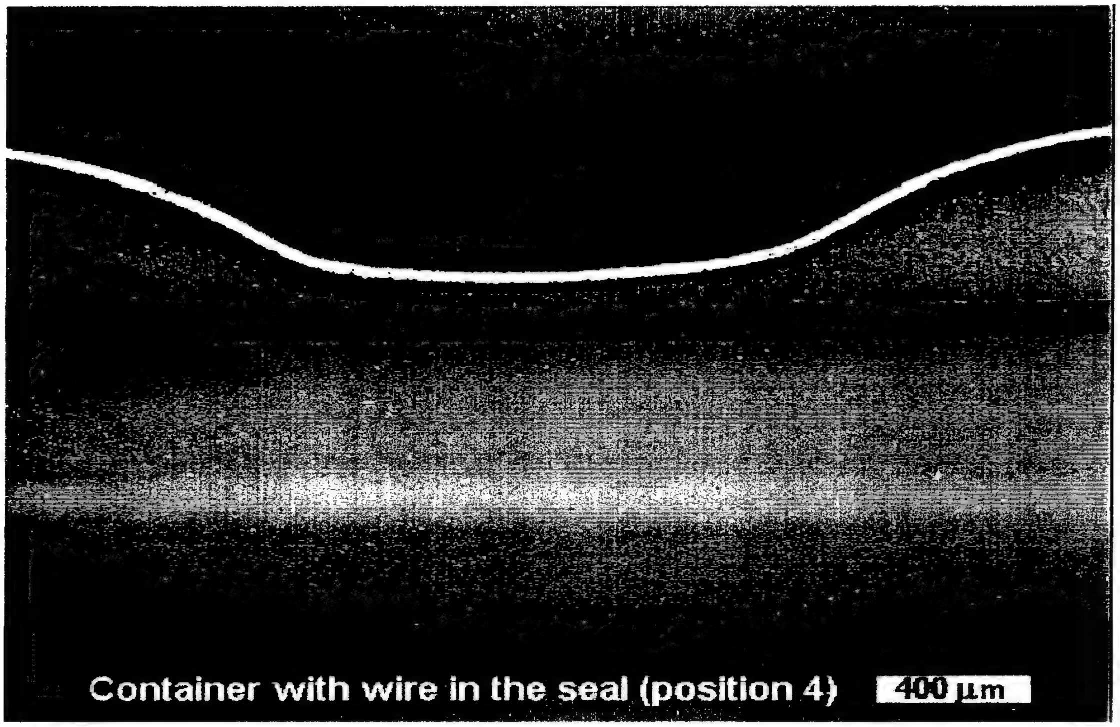

Figure 7. Optical microscopic picture of position A (undisturbed region)

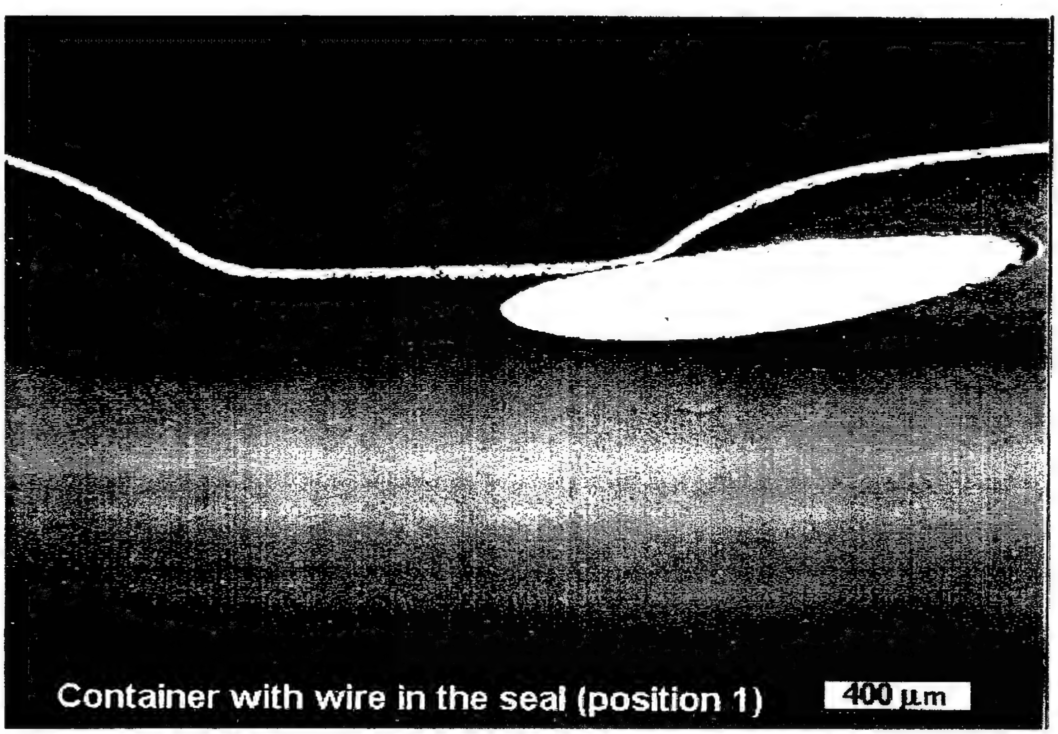

Figure 8. Optical Microscopic Picture of Position B (disturbed region including wire)

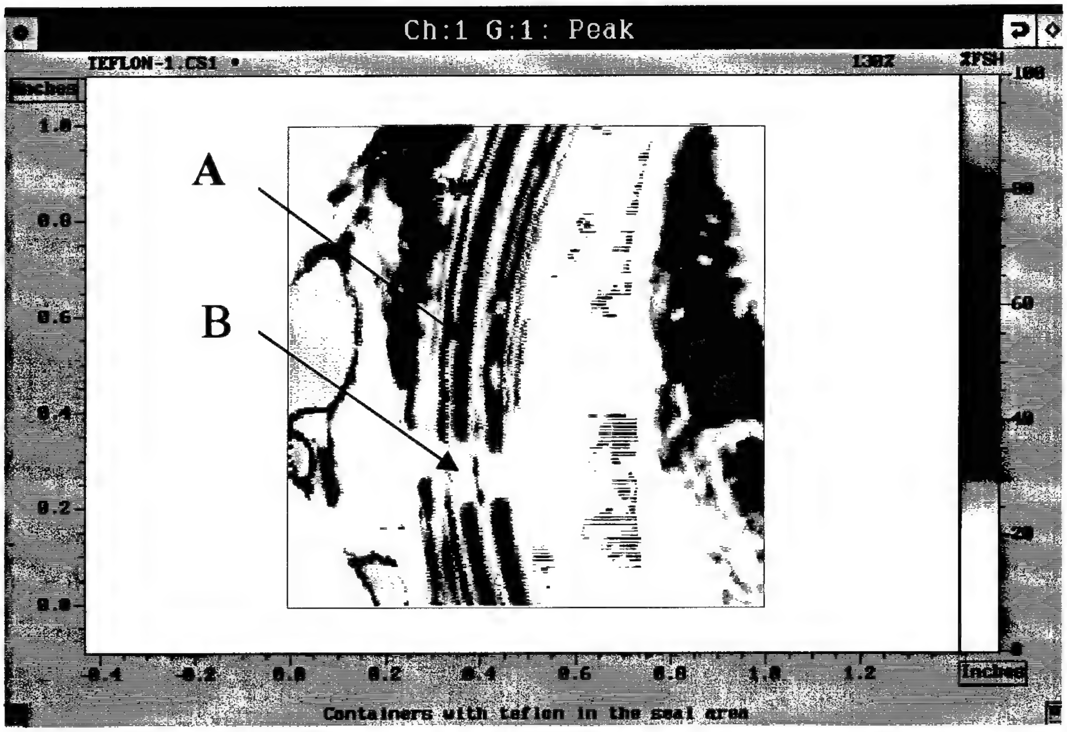

Figure 9. **Partial C-scan Presentation of a Semi-Rigid Cup with Teflon in the Seal Area**

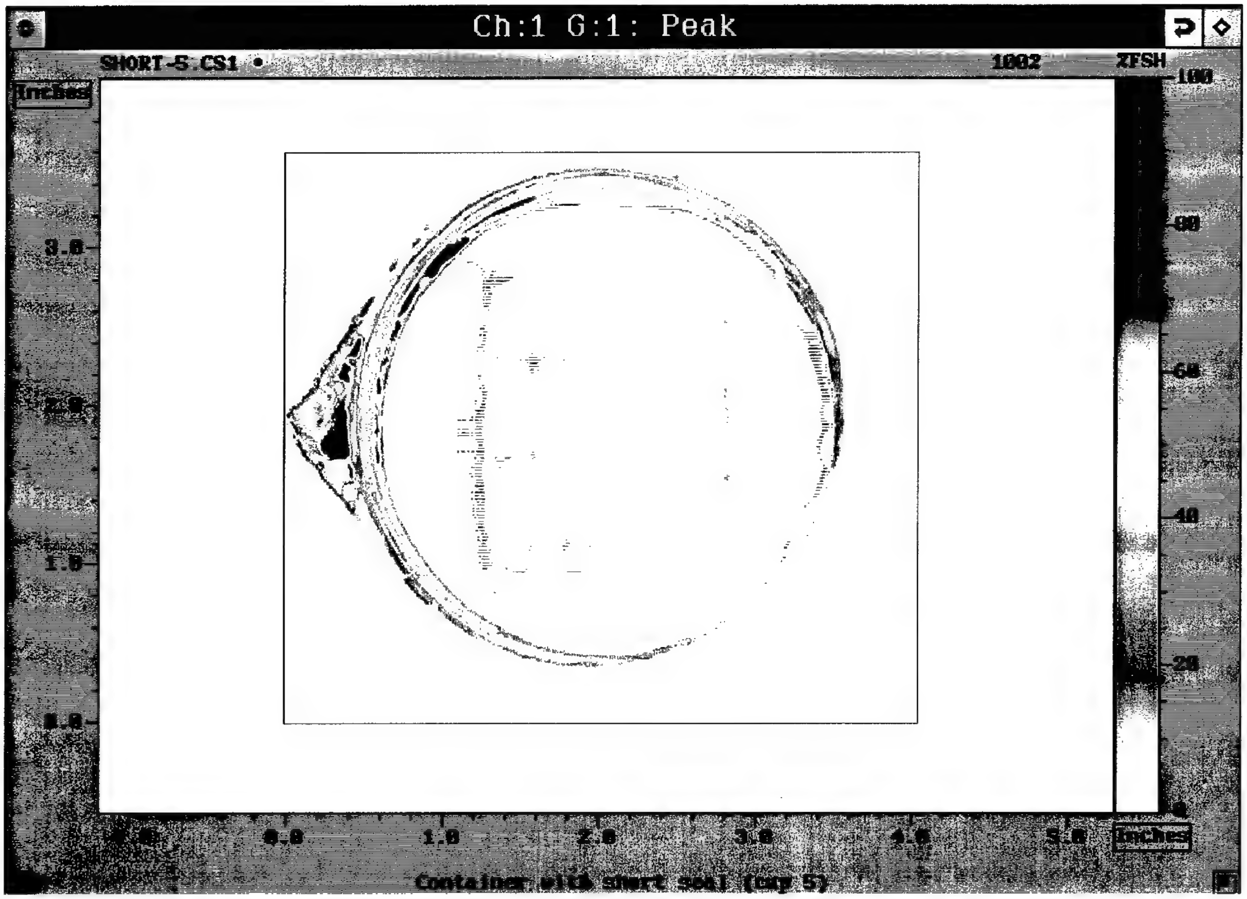

Figure 10 C-scan image of a semirigid plastic cup with short seal

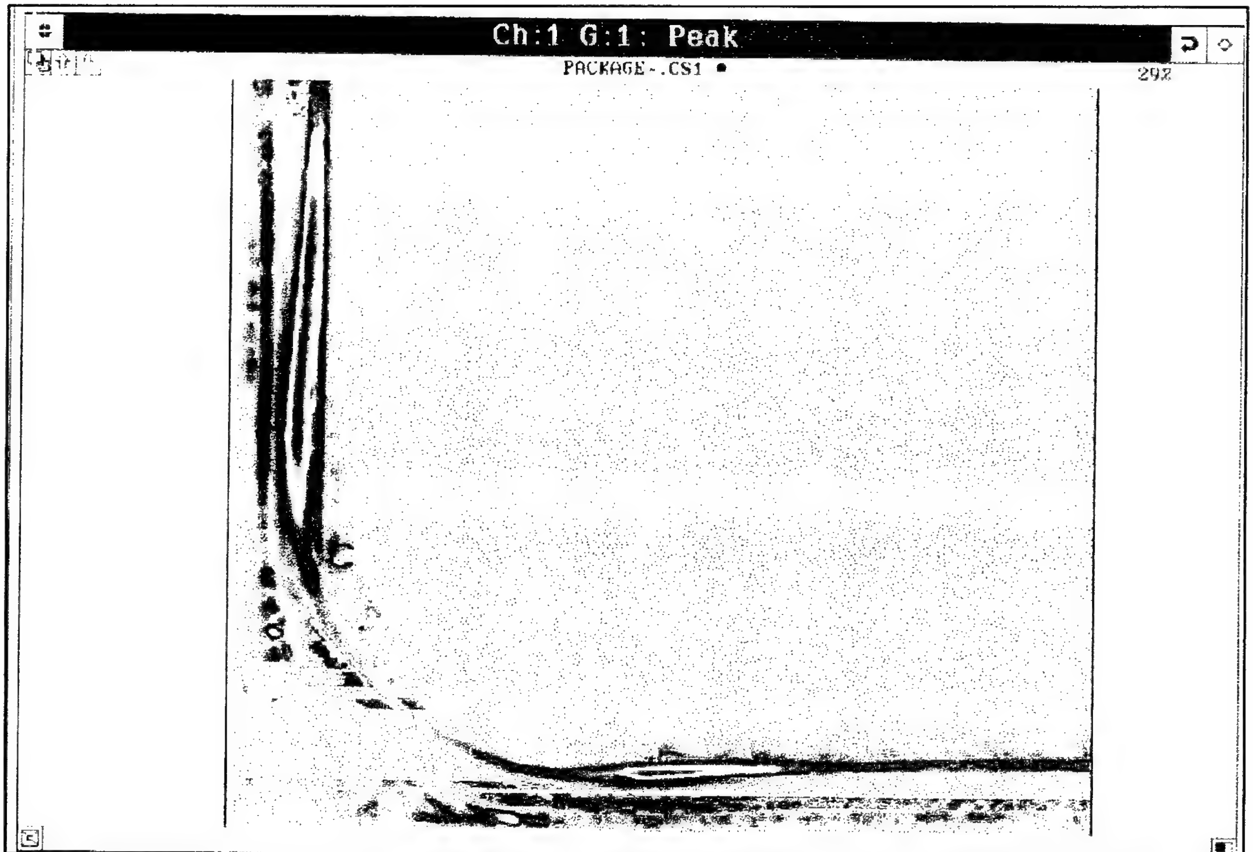

Figure 11 C-Scan Image of seal discontinuity on Poly-Tray

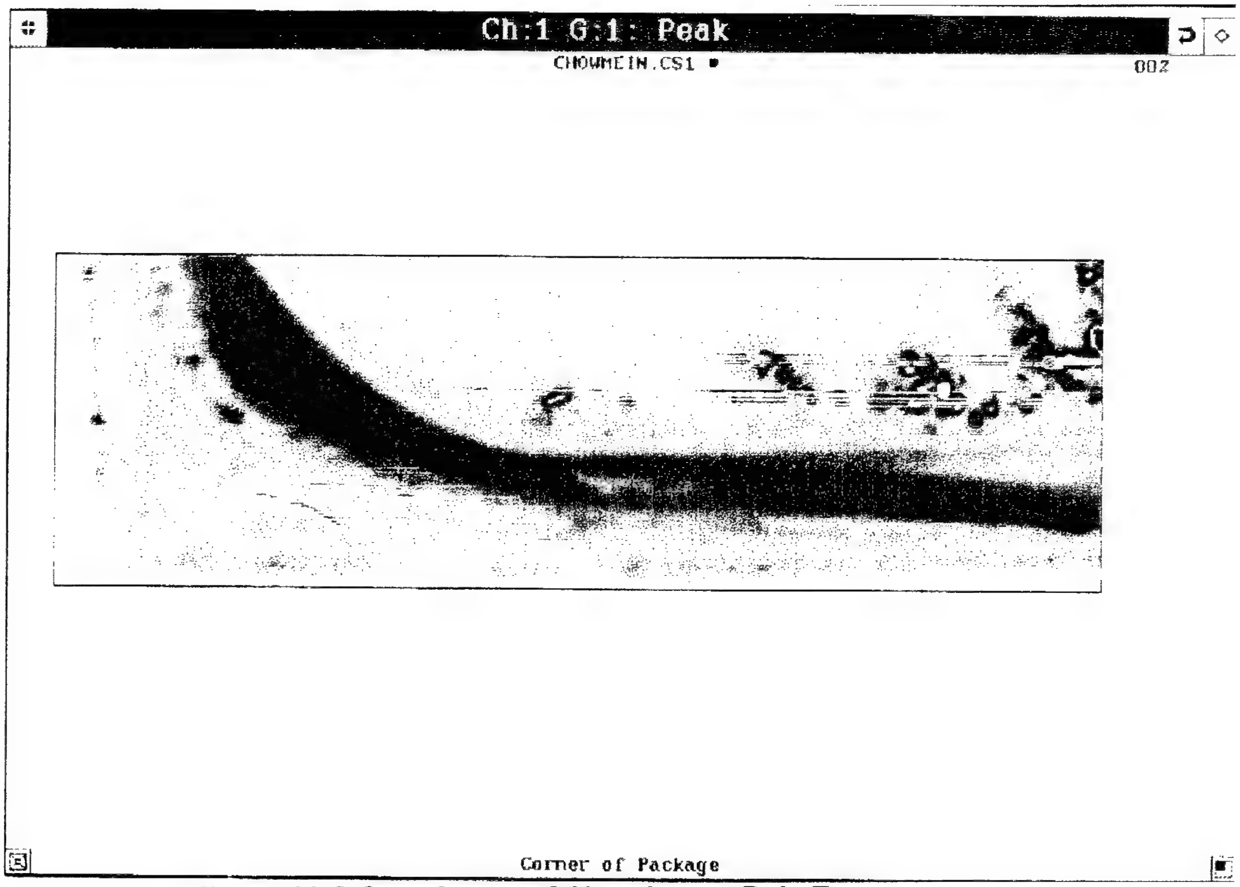

Figure 12 C-Scan Image of Abrasion on Poly-Tray

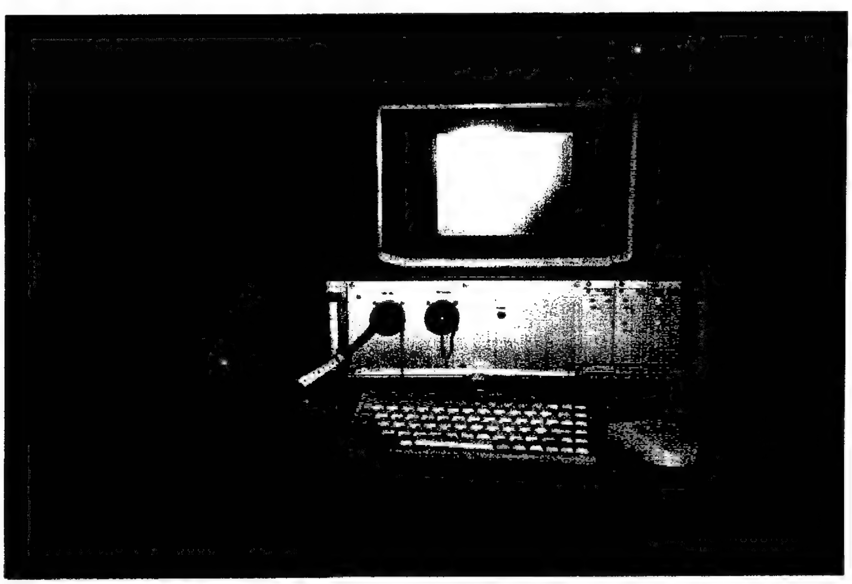

Figure 13 Picture of ALCAN Array Setup

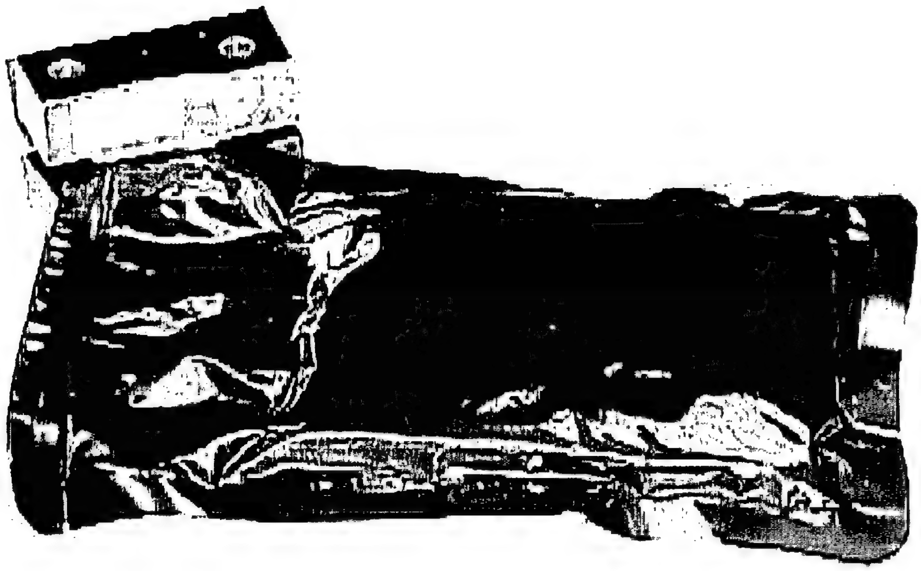

Figure 14 Ultrasonic 10-Element Array

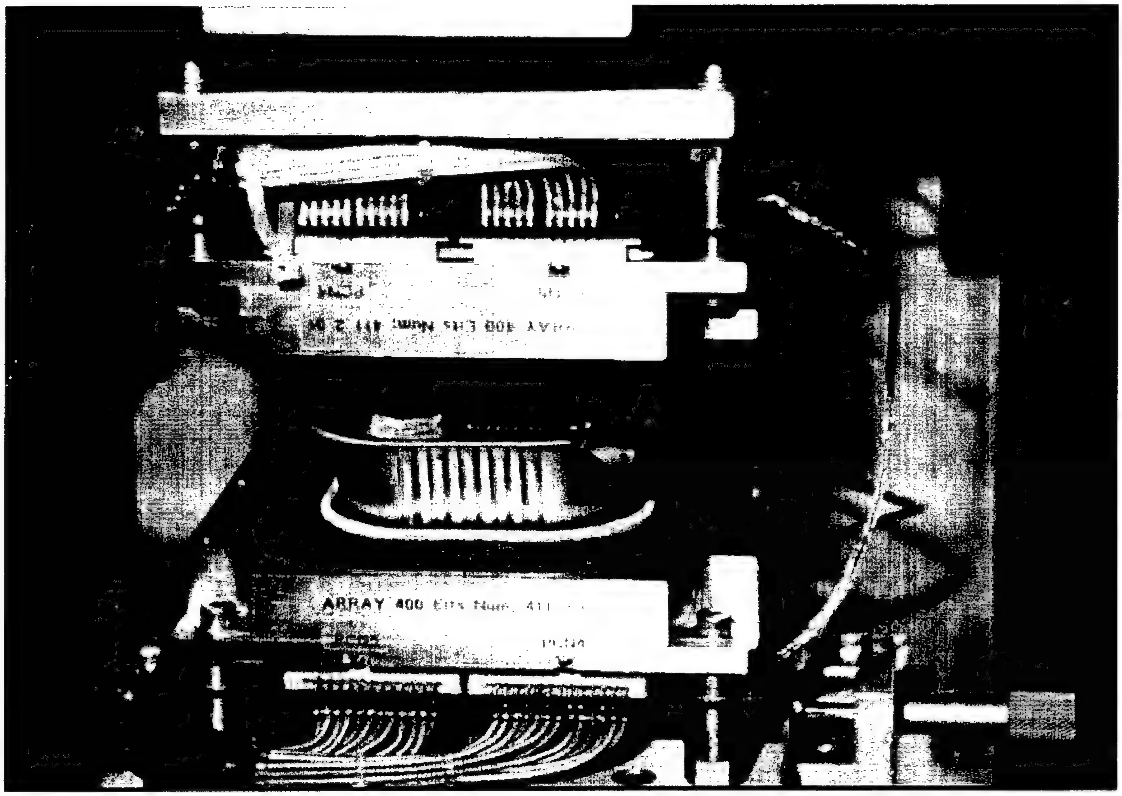

Figure 15 ALCAN Ultrasonic 400 Element Array

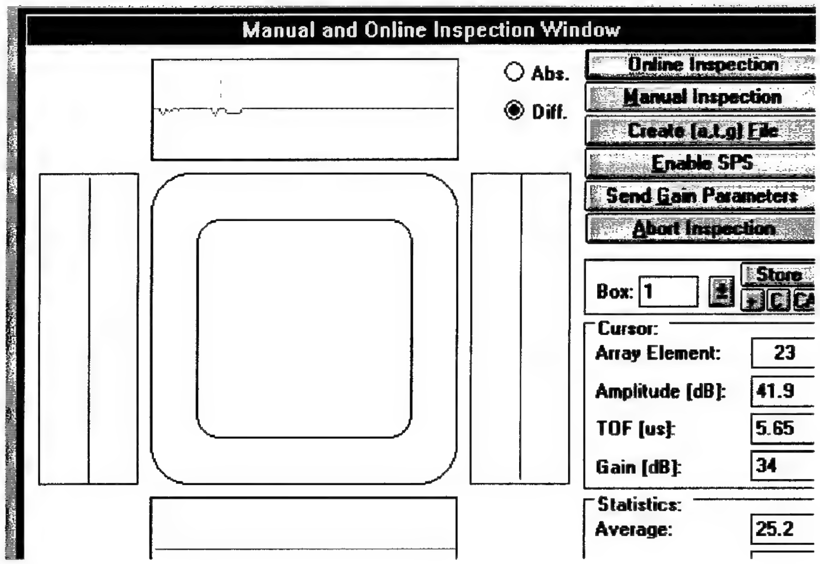

Figure 16 ALCAN ultrasonic scan of Good Seal

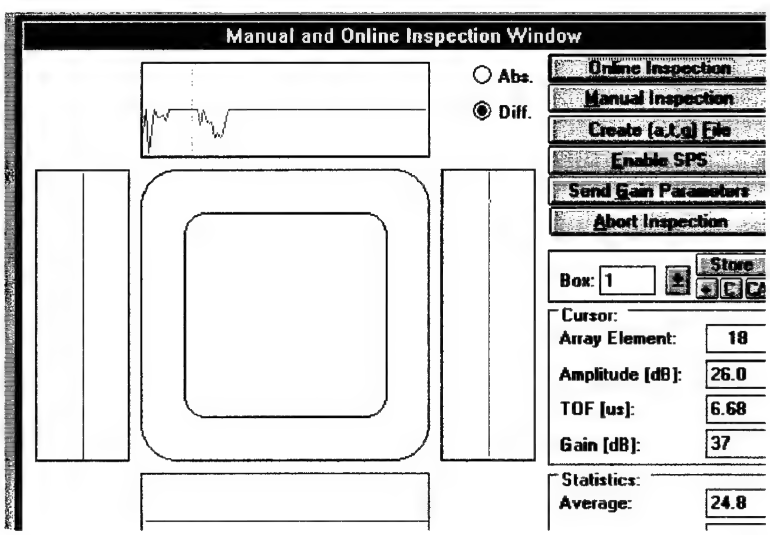

Figure 17 ALCAN Ultrasonic Scan of Short Seal

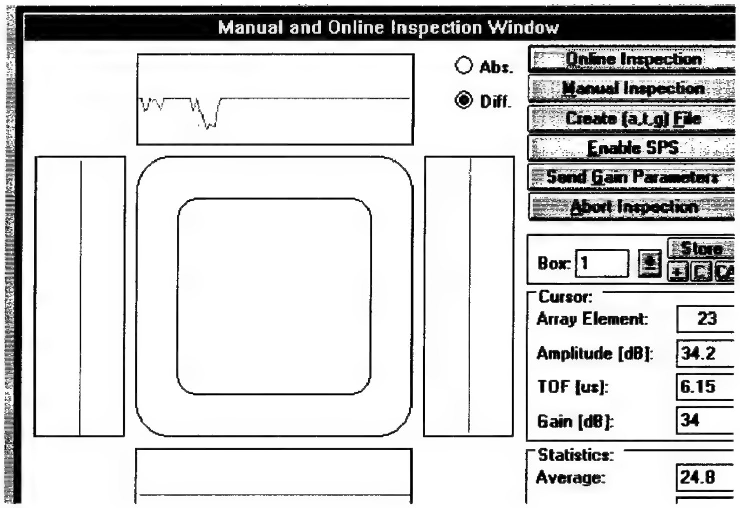

Figure 18 ALCAN Ultrasonic Scan of Contaminated Seal

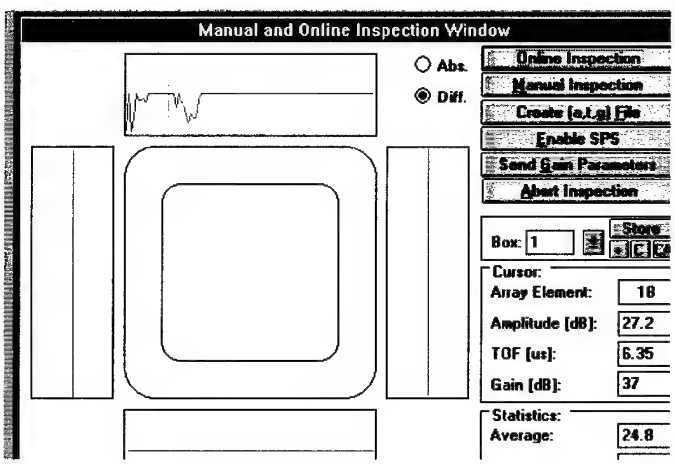

Figure 19 ALCAN Ultrasonic Scan of Contaminated Seal

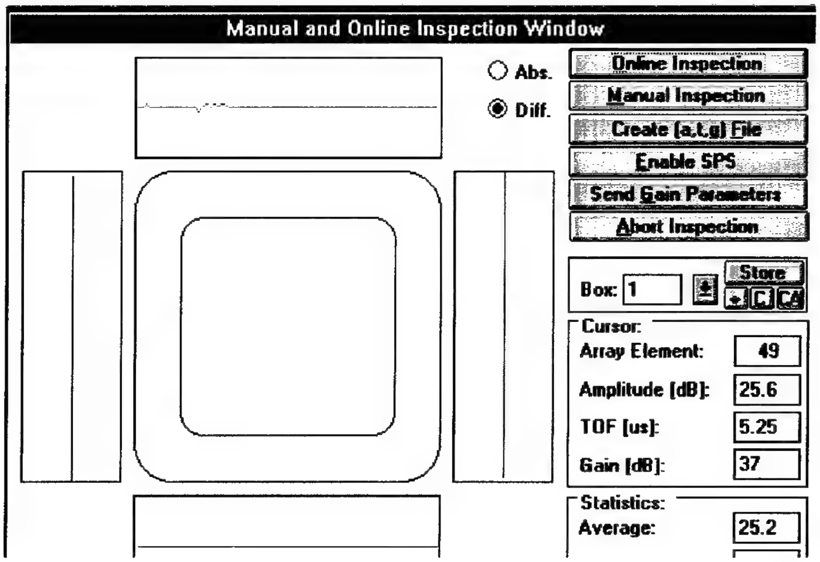

Figure 20 ALCAN Ultrasonic Scan of Good Seal

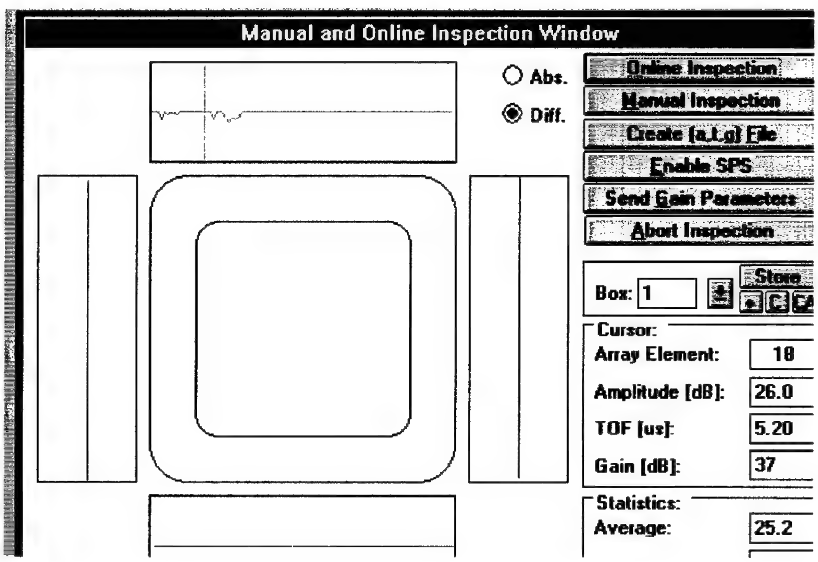

Figure 21 ALCAN Ultrasonic Scan of Contaminated Seal

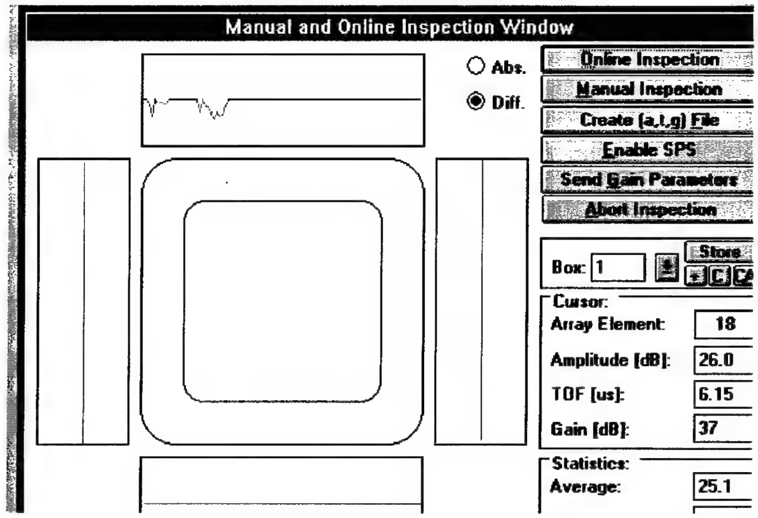

Figure 22 ALCAN Ultrasonic Scan of Contaminated Seal

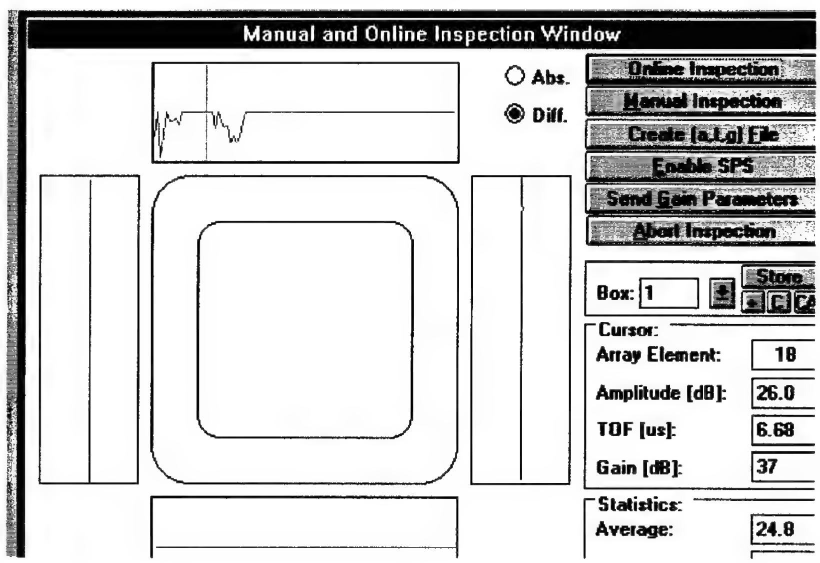

Figure 23 ALCAN Ultrasonic Scan of Contaminated Seal

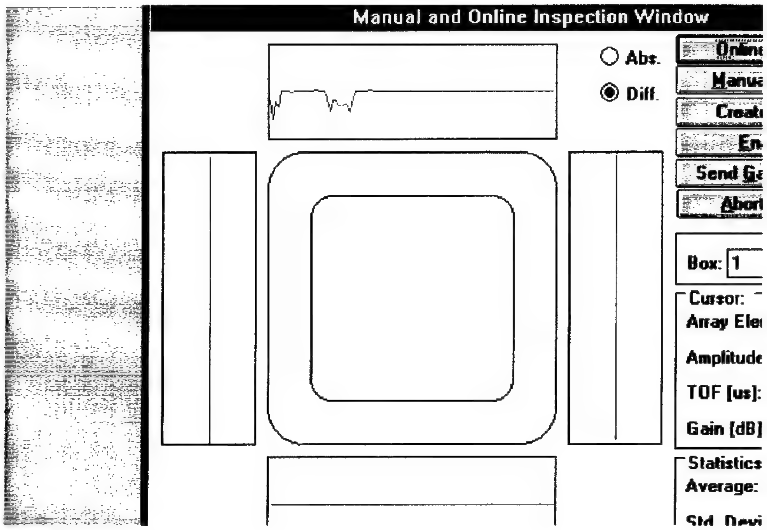

Figure 24 ALCAN Ultrasonic Scan of Contaminated Seal

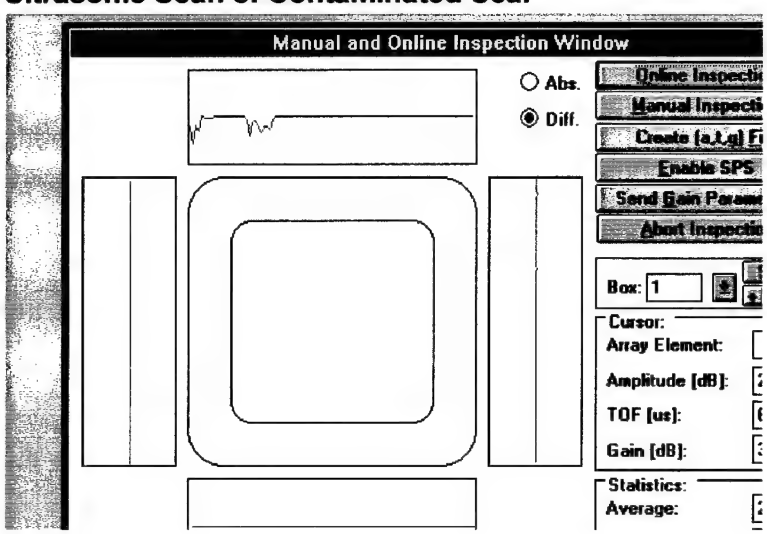

Figure 25 ALCAN Ultrasonic Scan of Contaminated Seal

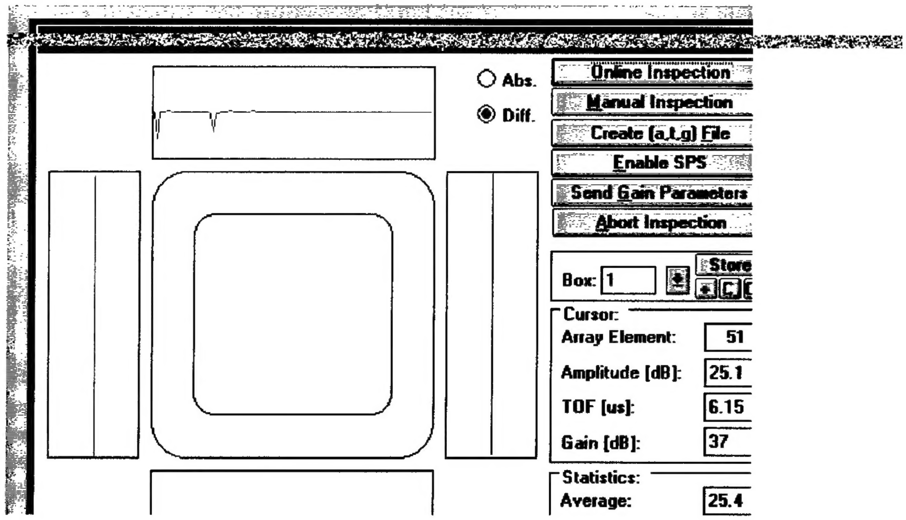

Figure 26 ALCAN Ultrasonic Scan of Good Seal

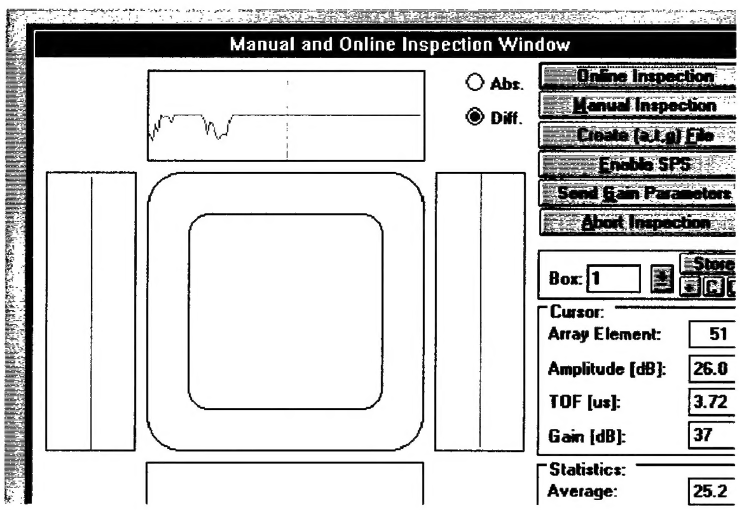

Figure 27 ALCAN Ultrasonic Scan of Contaminated Seal

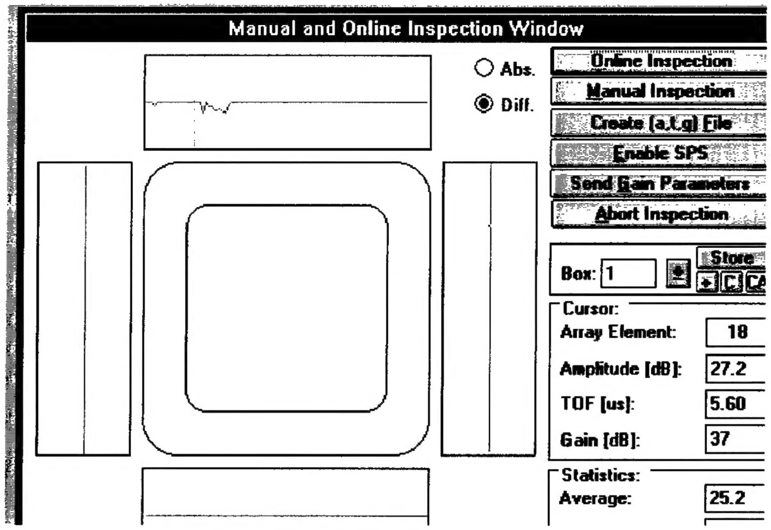

Figure 28 ALCAN Ultrasonic Scan of Contaminated Seal

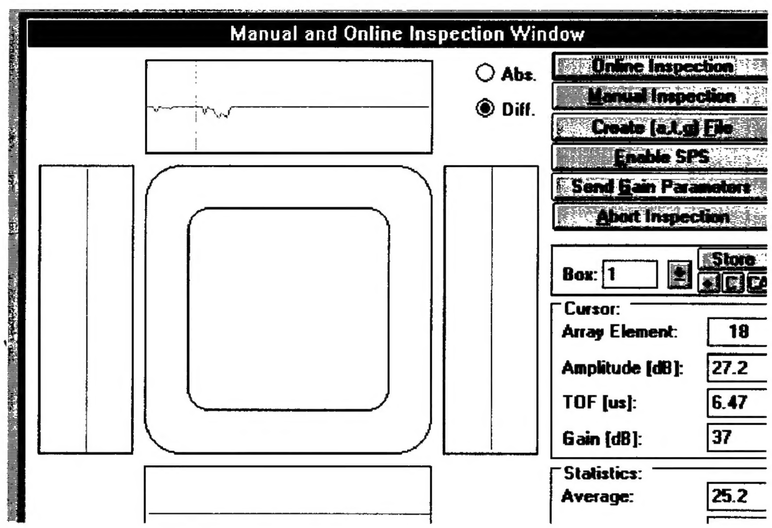

Figure 29 ALCAN Ultrasonic Scan of Contaminated Seal

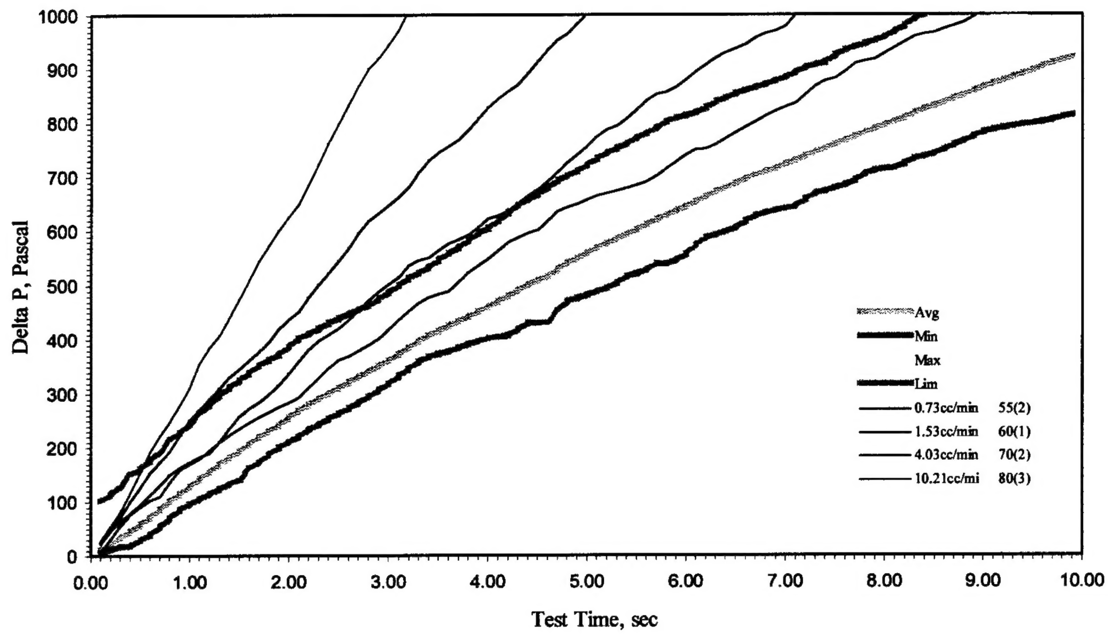

Figure 30 Pressure Difference versus Test time for Oatmeal Cookie Pouches during Leak Testing (test time: 10 s; equalizing time: 5 s)

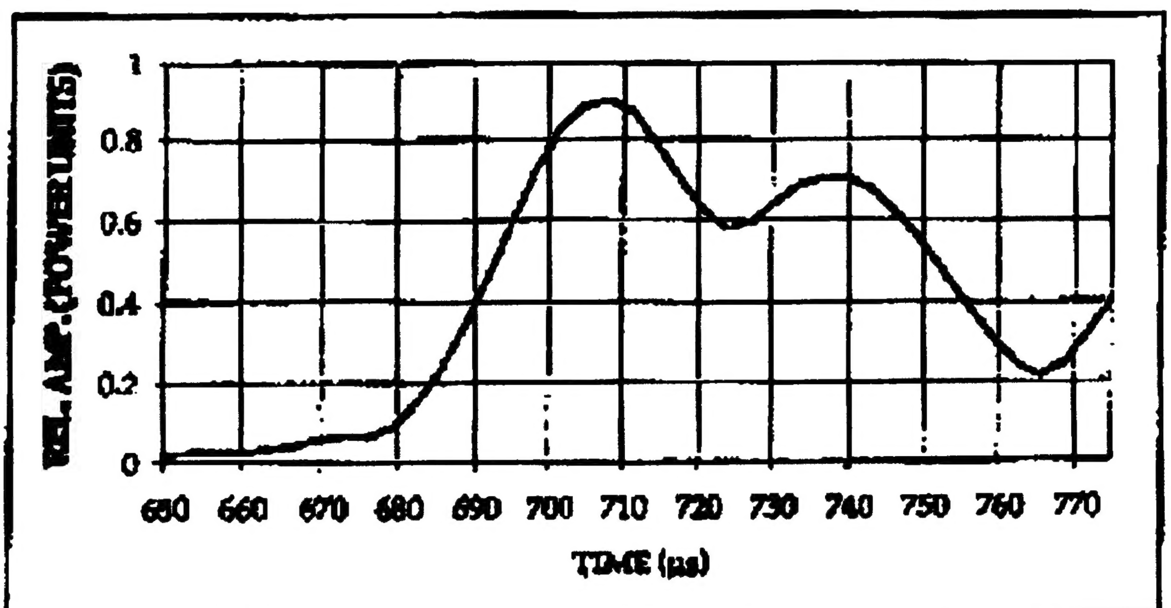

Figure 31 Transmitted signal through a package of meat indicates a good vacuum seal

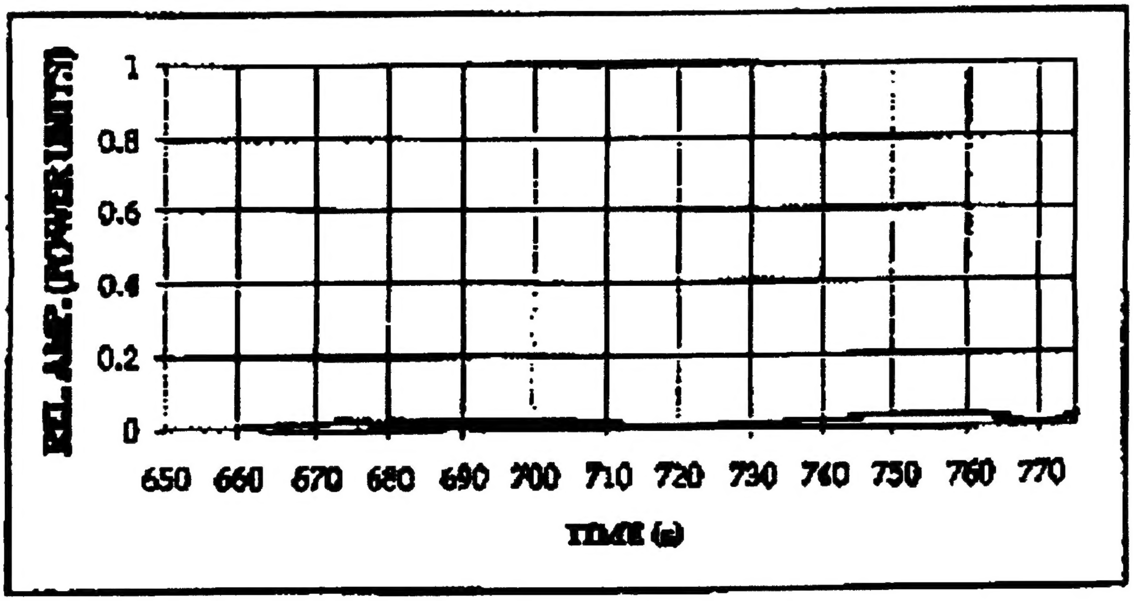

Figure 32 Absence of transmitted signal indicates a bad vacuum seal

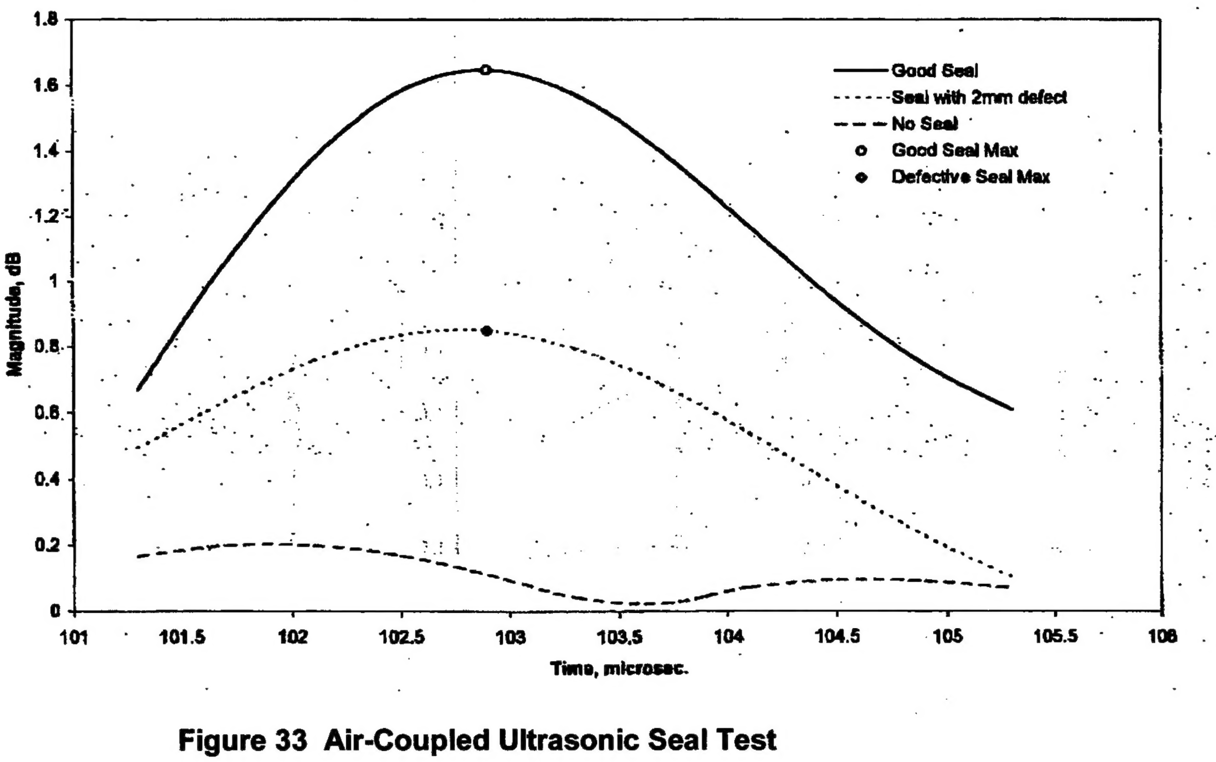

Figure 33 Air-Coupled Ultrasonic Seal Test